Visualization Analysis & Design

Tamara Munzner
Department of Computer Science
University of British Columbia

Microsoft Research
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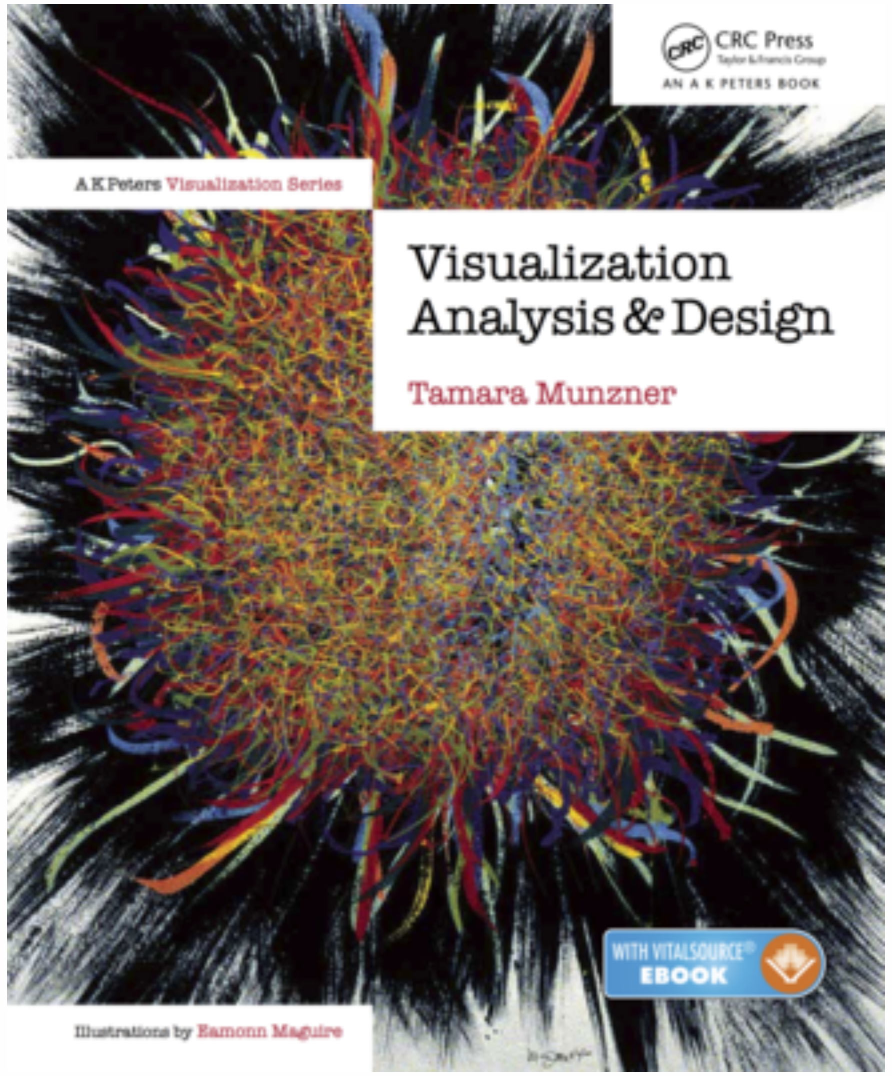
http://www.cs.ubc.ca/~tmm/talks.html#vad15seattle



Defining visualization (vis)

Computer-based visualization systems provide visual representations of datasets designed to help people carry out tasks more effectively.

Why?...

Why have a human in the loop?

Computer-based visualization systems provide visual representations of datasets designed to help people carry out tasks more effectively.

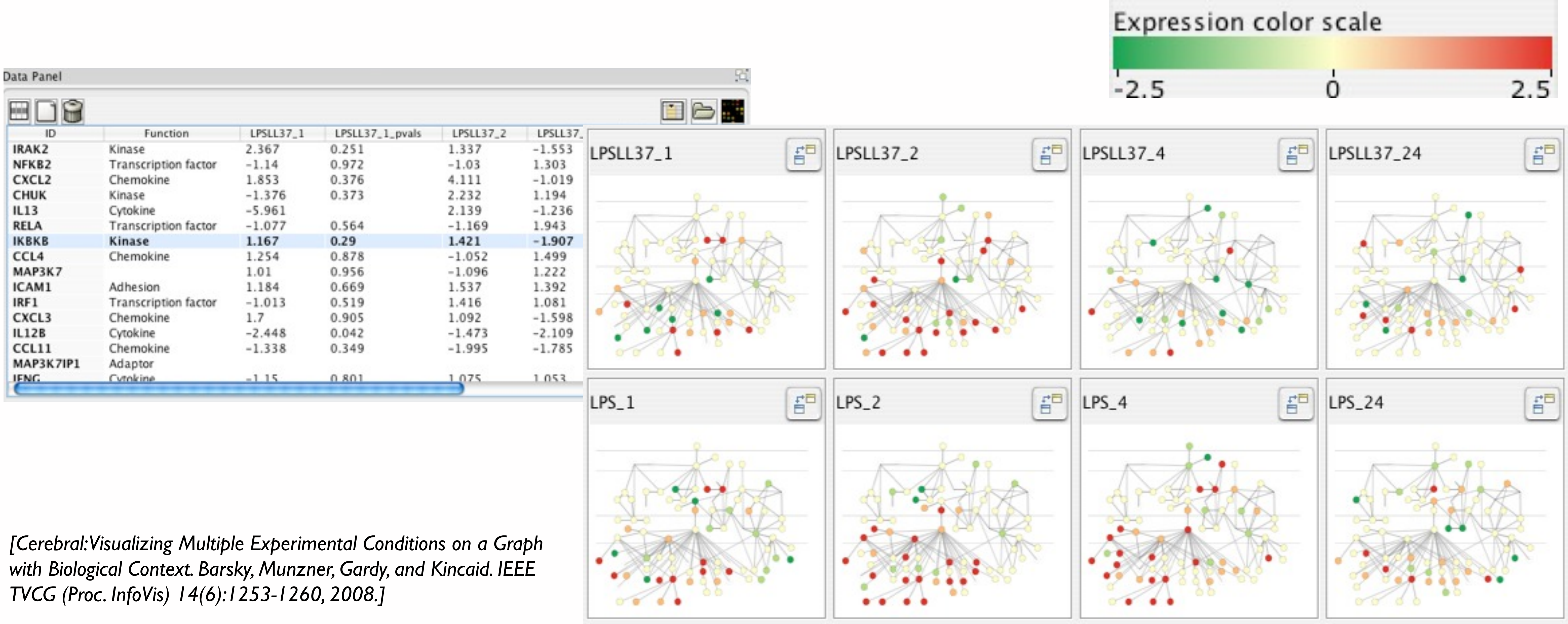
Visualization is suitable when there is a need to augment human capabilities rather than replace people with computational decision-making methods.

- don’t need vis when fully automatic solution exists and is trusted
- many analysis problems ill-specified
  - don’t know exactly what questions to ask in advance
- possibilities
  - long-term use for end users (e.g. exploratory analysis of scientific data)
  - presentation of known results
  - stepping stone to better understanding of requirements before developing models
  - help developers of automatic solution refine/debug, determine parameters
  - help end users of automatic solutions verify, build trust

Why use an external representation?

Computer-based visualization systems provide visual representations of datasets designed to help people carry out tasks more effectively.

- external representation: replace cognition with perception



[Cerebral: Visualizing Multiple Experimental Conditions on a Graph with Biological Context. Barsky, Munzner, Gardy, and Kincaid. IEEE TVCG (Proc. InfoVis) 14(6):1253-1260, 2008.]

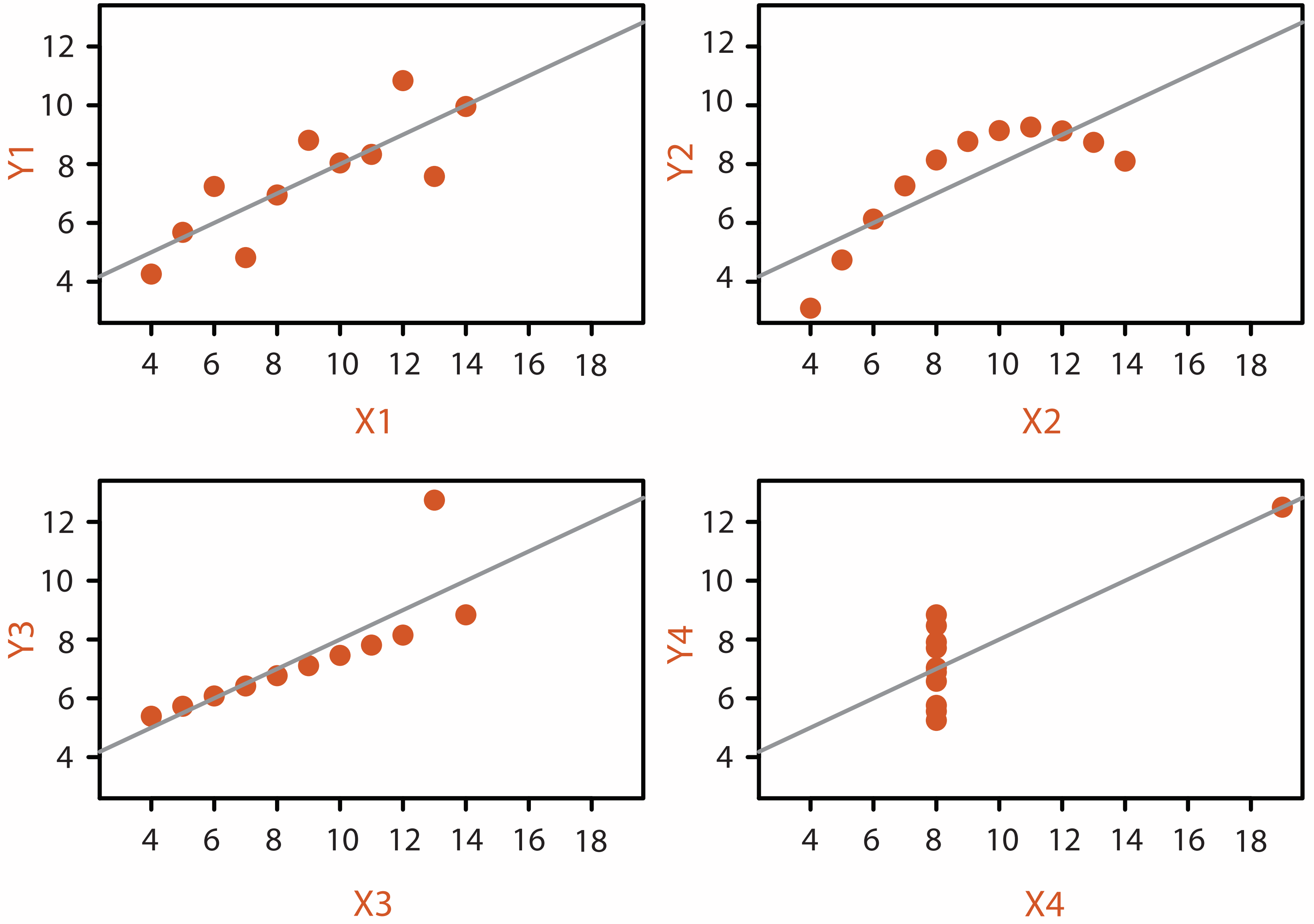
Why represent all the data?

Computer-based visualization systems provide visual representations of datasets designed to help people carry out tasks more effectively.

- summaries lose information, details matter
  - confirm expected and find unexpected patterns
  - assess validity of statistical model

Anscombe's Quartet

Identical statistics	
x mean	9
x variance	10
y mean	8
y variance	4
x/y correlation	1



Why are there resource limitations?

Vis designers must take into account three very different kinds of resource limitations: those of computers, of humans, and of displays.

- computational limits
  - processing time
  - system memory
- human limits
  - human attention and memory
- display limits
  - pixels are precious resource, the most constrained resource
  - **information density**: ratio of space used to encode info vs unused whitespace
    - tradeoff between clutter and wasting space, find sweet spot between dense and sparse

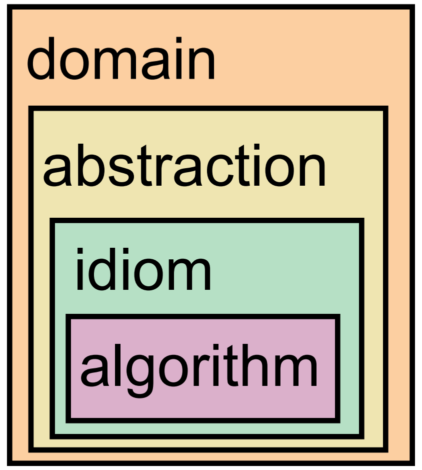
Why focus on tasks and effectiveness?

Computer-based visualization systems provide visual representations of datasets designed to help people carry out tasks more effectively.

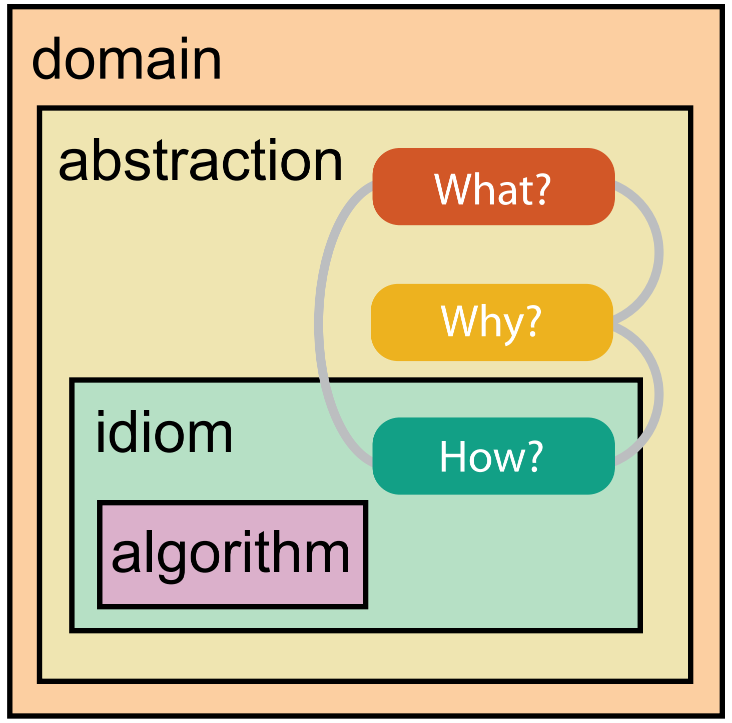
- what counts as effective?
  - novel: enable entirely new kinds of analysis
  - faster: speed up existing workflows
- most possibilities ineffective
  - increase chance of finding good solutions by understanding full space of possibilities
- tasks serve as constraint on design (as does data)
  - representations do not serve all tasks equally!

Analysis framework: Four levels, three questions

- *domain* situation
  – who are the target users?
- *abstraction*
  – translate from specifics of domain to vocabulary of vis
  - **what** is shown? **data abstraction**
  - **why** is the user looking at it? **task abstraction**
- *idiom*
  - **how** is it shown?
    - **visual encoding idiom**: how to draw
    - **interaction idiom**: how to manipulate
- *algorithm*
  – efficient computation

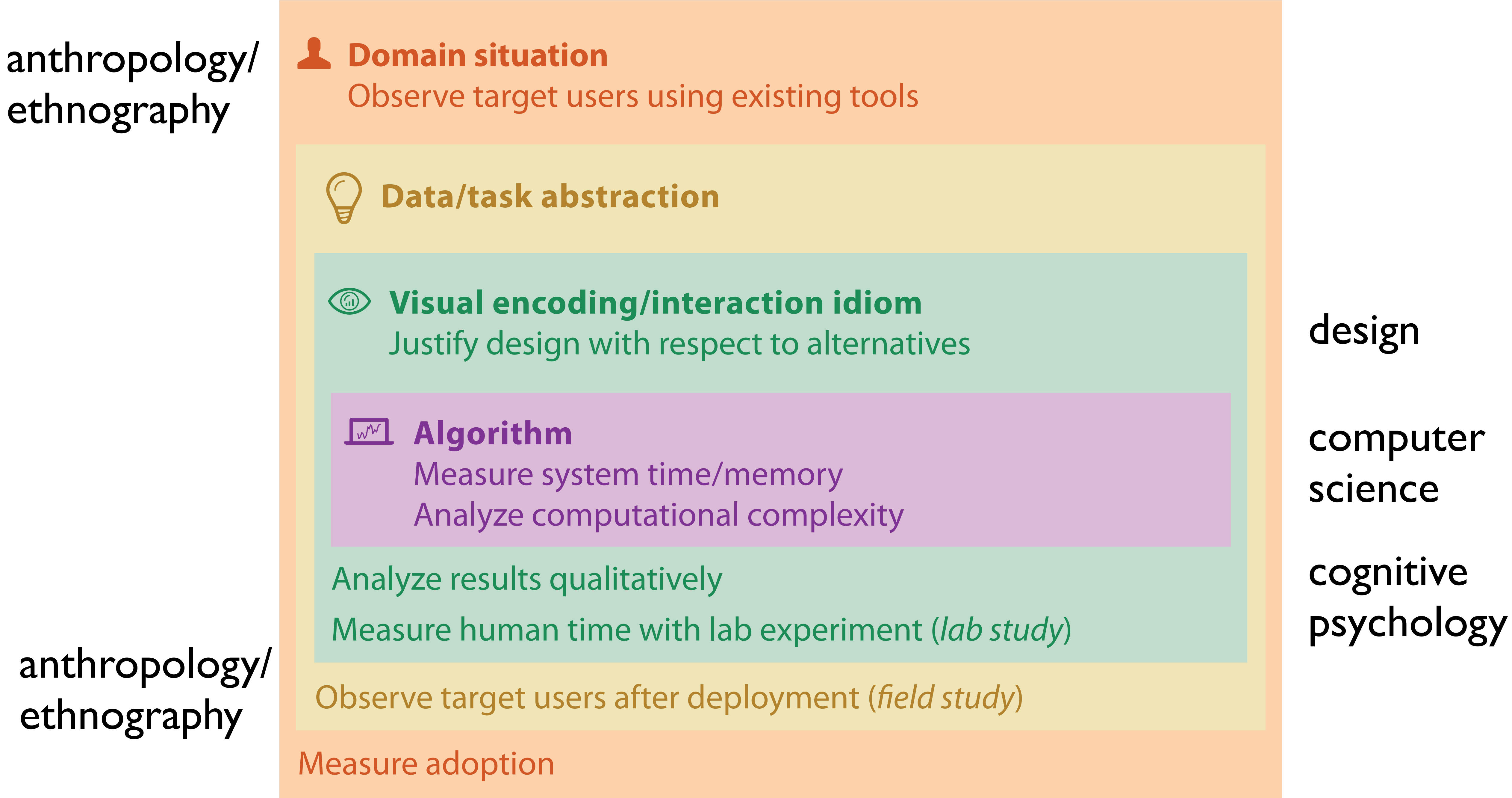


[A Nested Model of Visualization Design and Validation.
Munzner. IEEE TVCG 15(6):921-928, 2009 (Proc. InfoVis 2009).]



[A Multi-Level Typology of Abstract Visualization Tasks
Brehmer and Munzner. IEEE TVCG 19(12):2376-2385, 2013 (Proc. InfoVis 2013).]

Validation methods from different fields for each level



- mismatch: cannot show idiom good with system timings
- mismatch: cannot show abstraction good with lab study

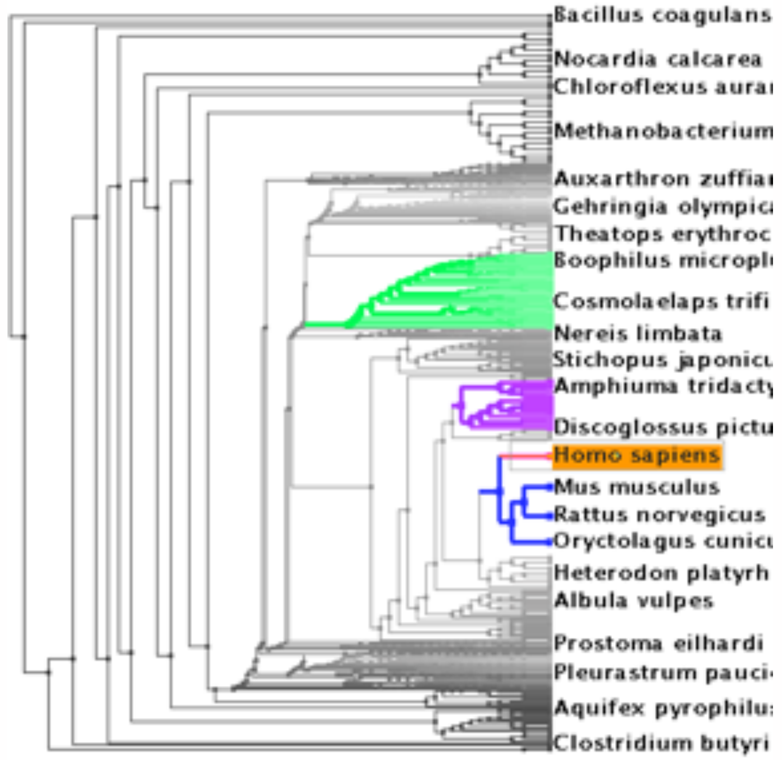
Why analyze?

- imposes a structure on huge design space
  – scaffold to help you think systematically about choices
  – analyzing existing as stepping stone to designing new

SpaceTree

[SpaceTree: Supporting Exploration in Large Node Link Tree, Design Evolution and Empirical Evaluation. Grosjean, Plaisant, and Bederson. Proc. InfoVis 2002, p 57–64.]

TreeJuxtaposer



[TreeJuxtaposer: Scalable Tree Comparison Using Focus +Context With Guaranteed Visibility. ACM Trans. on Graphics (Proc. SIGGRAPH) 22:453– 462, 2003.]

What?

- Tree

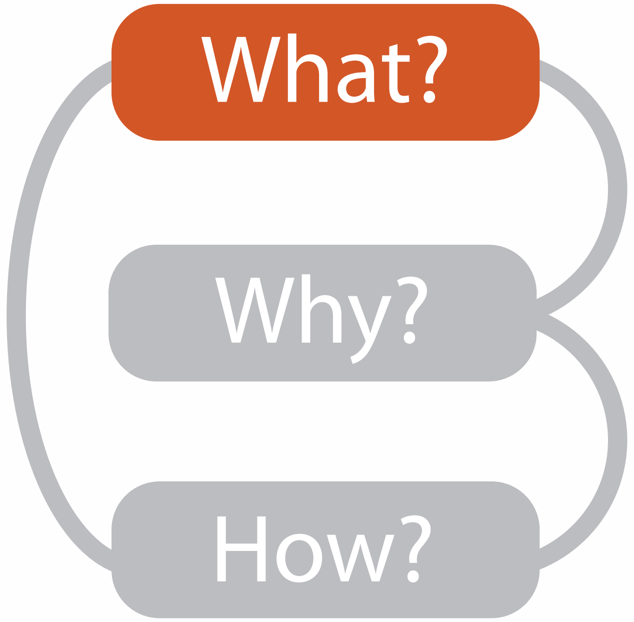
Why?

- Actions
  - → Present → Locate → Identify
- Targets
  - → Path between two nodes

How?

- SpaceTree
  - → Encode → Navigate → Select → Filter → Aggregate
- TreeJuxtaposer
  - → Encode → Navigate → Select → Arrange

What?
Why?
How?



What?

Datasets

Data Types

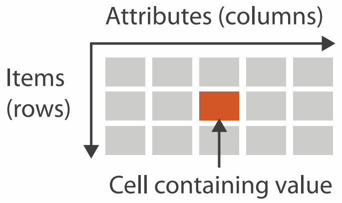
- Items
- Attributes
- Links
- Positions
- Grids

Data and Dataset Types

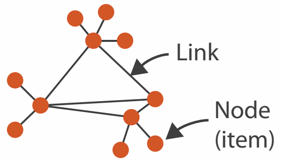
Tables	Networks & Trees	Fields	Geometry	Clusters, Sets, Lists
Items	Items (nodes)	Grids	Items	Items
Attributes	Links	Positions	Positions	
	Attributes	Attributes		

Dataset Types

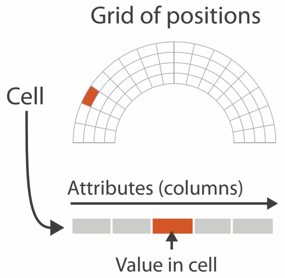
- Tables



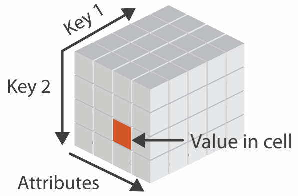
- Networks



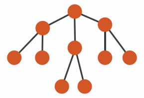
- Fields (Continuous)



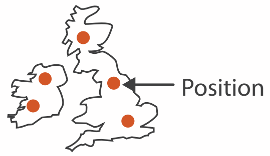
- *Multidimensional Table*



- *Trees*



- Geometry (Spatial)



Dataset Availability

- Static

- Dynamic

Attributes

Attribute Types

- Categorical

- Ordered
  - *Ordinal*

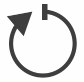
  - *Quantitative*

Ordering Direction

- Sequential

- Diverging

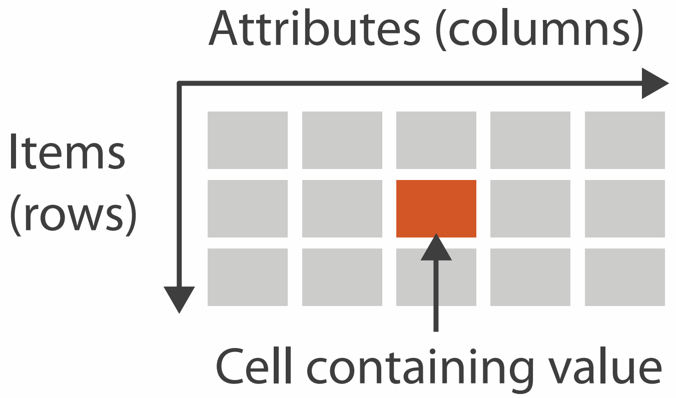
- Cyclic



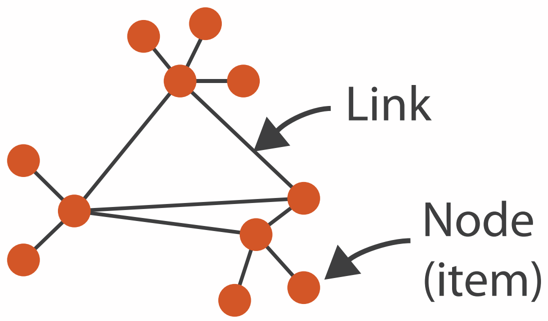
Dataset and data types

Dataset Types

Tables

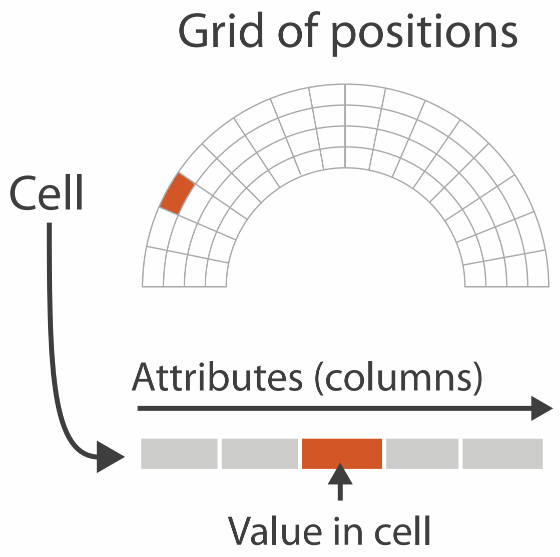


Networks

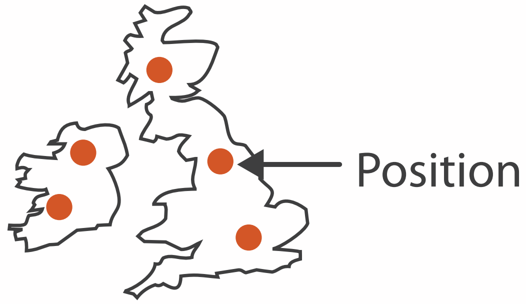


Spatial

Fields (Continuous)



Geometry (Spatial)

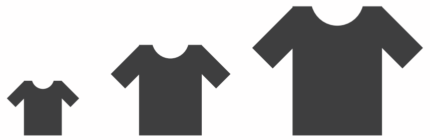


Attribute Types

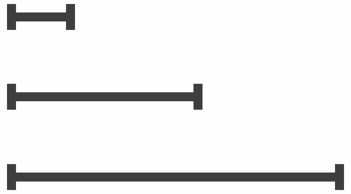
Categorical

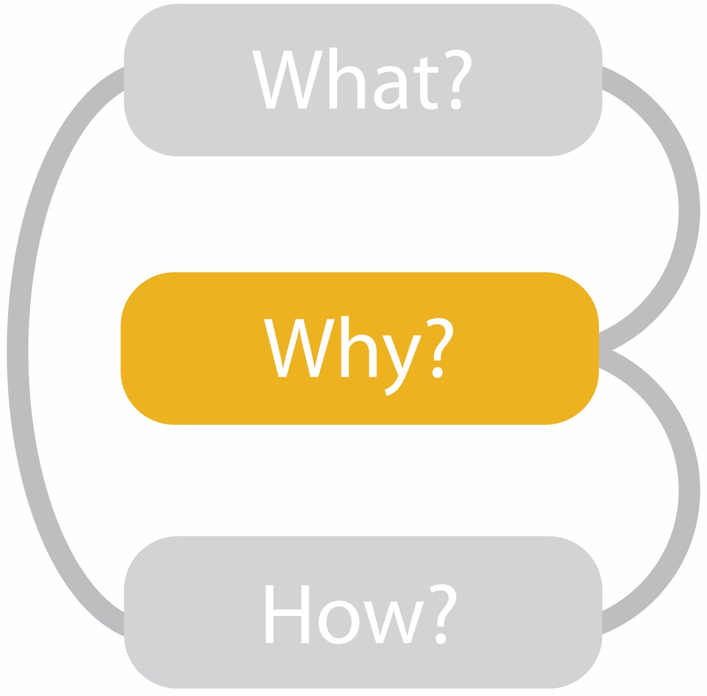
Ordered

Ordinal

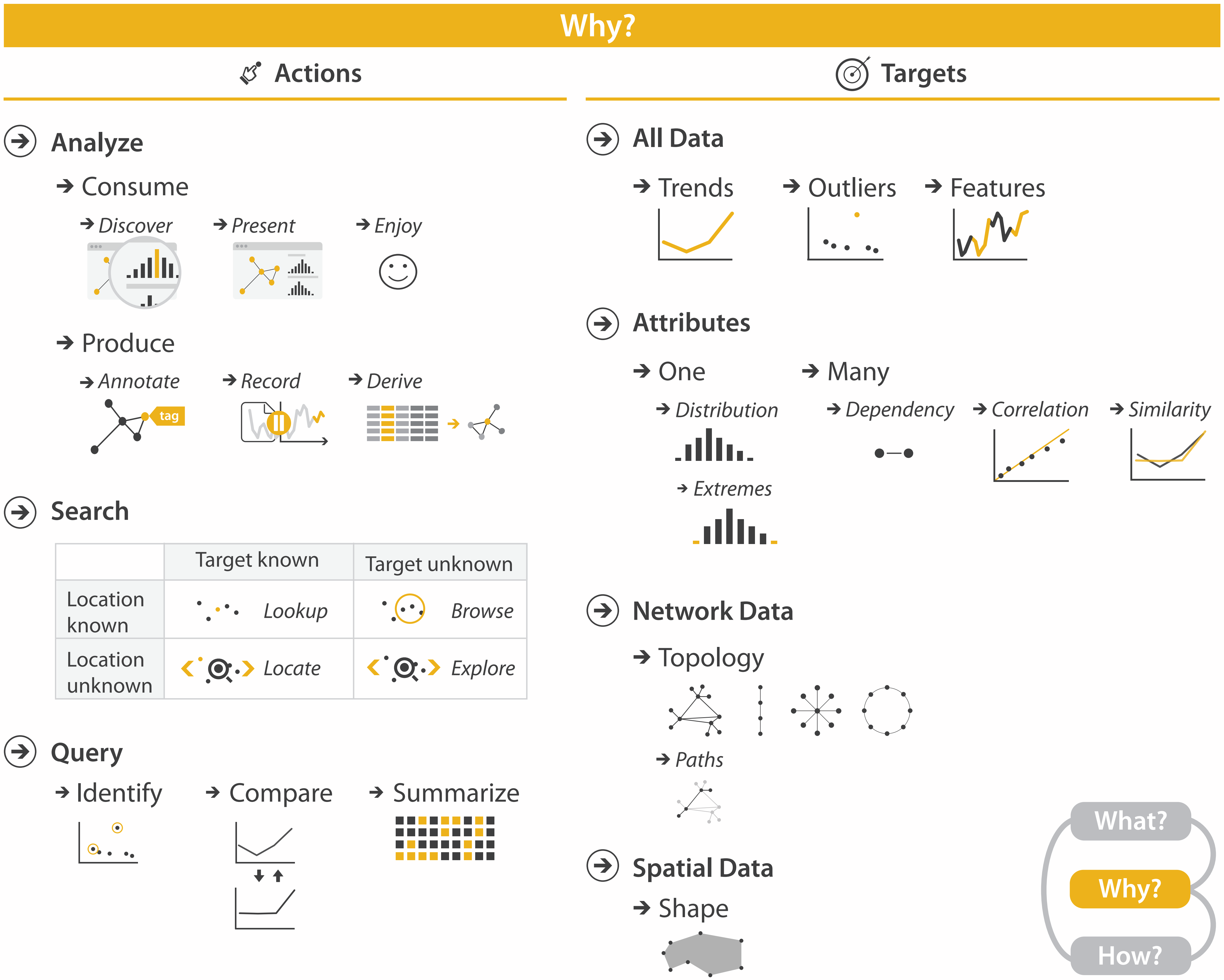


Quantitative



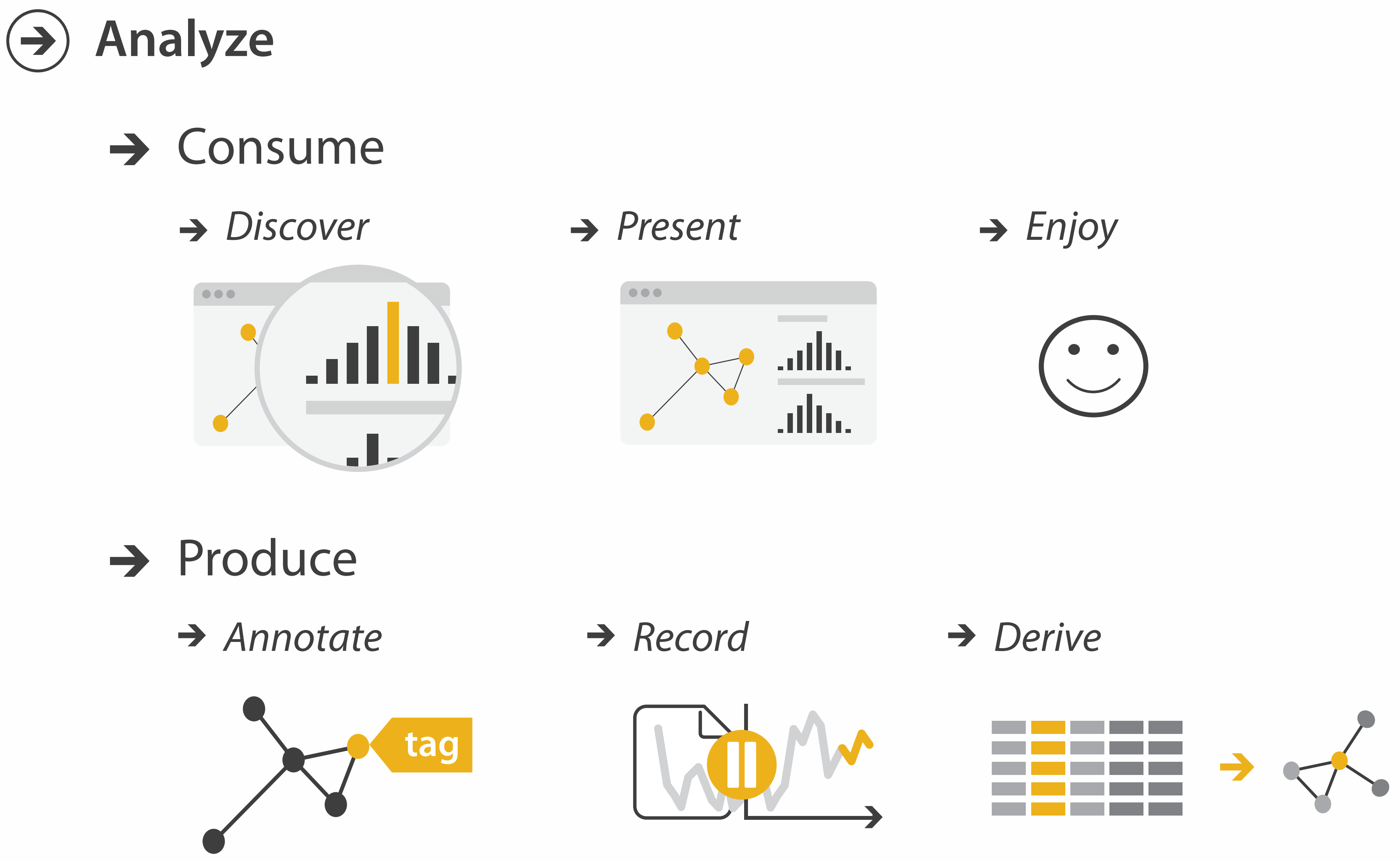


- {action, target} pairs
  - *discover distribution*
  - *compare trends*
  - *locate outliers*
  - *browse topology*



Actions 1: Analyze

- consume
  - discover vs present
    - classic split
    - aka explore vs explain
  - enjoy
    - newcomer
    - aka casual, social
- produce
  - annotate, record
  - derive
    - crucial design choice



Actions II: Search

- what does user know?
  - target, location

Search

	Target known	Target unknown
Location known	*Lookup*	*Browse*
Location unknown	*Locate*	*Explore*

Actions III: Query

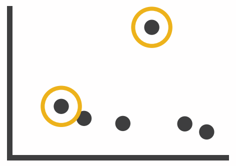
- what does user know?
  - target, location
- how much of the data matters?
  - one, some, all

Search

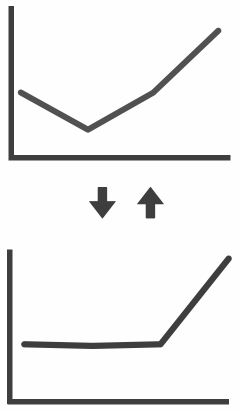
	Target known	Target unknown
Location known	*Lookup*	*Browse*
Location unknown	*Locate*	*Explore*

Query

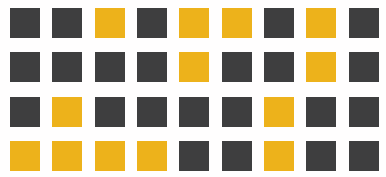
→ Identify



→ Compare



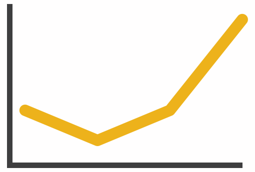
→ Summarize



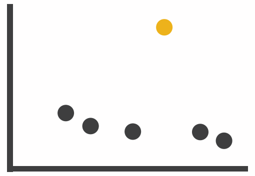
Targets

➔ All Data

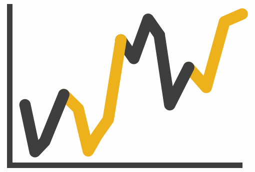
- ➔ Trends



- ➔ Outliers

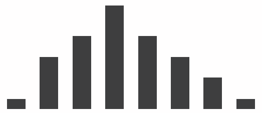


- ➔ Features

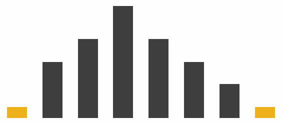


➔ Attributes

- ➔ One
  - ➔ *Distribution*

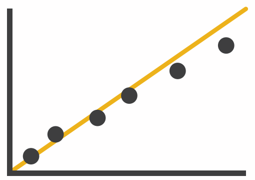


  - ➔ *Extremes*

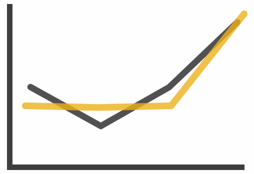


- ➔ Many
  - ➔ *Dependency*

  - ➔ *Correlation*

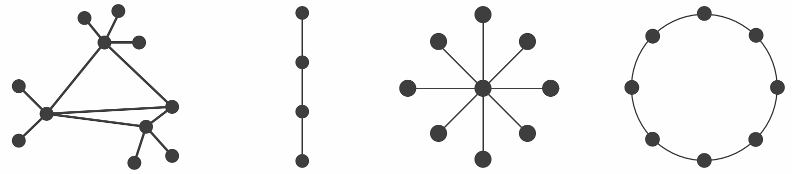


  - ➔ *Similarity*

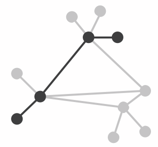


➔ Network Data

- ➔ Topology

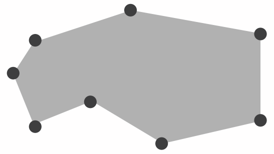


  - ➔ *Paths*



➔ Spatial Data

- ➔ Shape



How?

Encode

Arrange
- Express
- Separate
- Order
- Align
- Use

Map
from categorical and ordered attributes

- Color
  - *Hue*
  - *Saturation*
  - *Luminance*
- Size, Angle, Curvature, ...
- Shape
- Motion
  Direction, Rate, Frequency, ...

Manipulate

Change

Select

Navigate

Facet

Juxtapose

Partition

Superimpose

Reduce

Filter

Aggregate

Embed

What?

Why?

How?

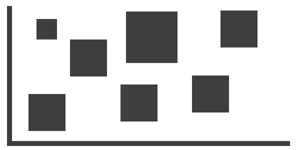
How to encode: Arrange space, map channels

Encode

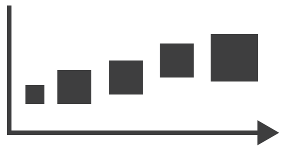
Arrange

→ Express

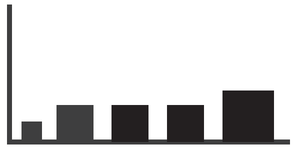
→ Separate



→ Order



→ Align



→ Use

Map

from categorical and ordered attributes

→ Color

→ *Hue*

→ *Saturation*

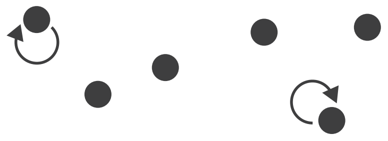
→ *Luminance*

→ Size, Angle, Curvature, ...

→ Shape

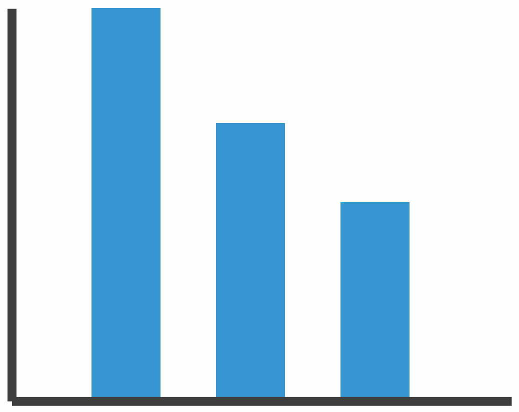
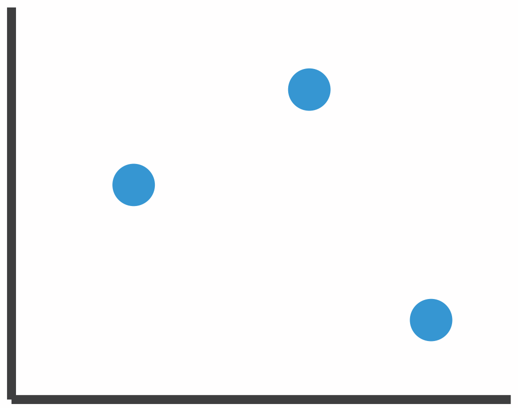
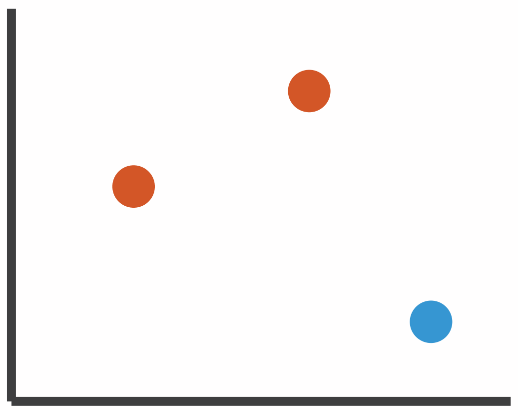
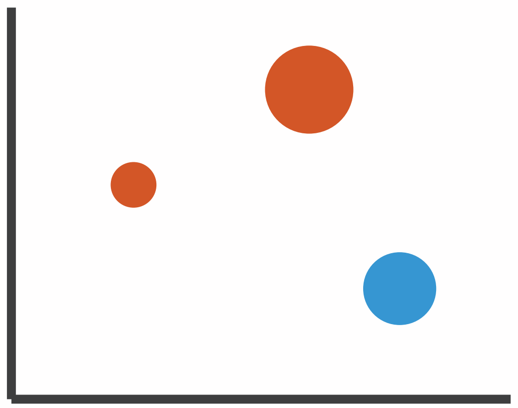
→ Motion

Direction, Rate, Frequency, ...



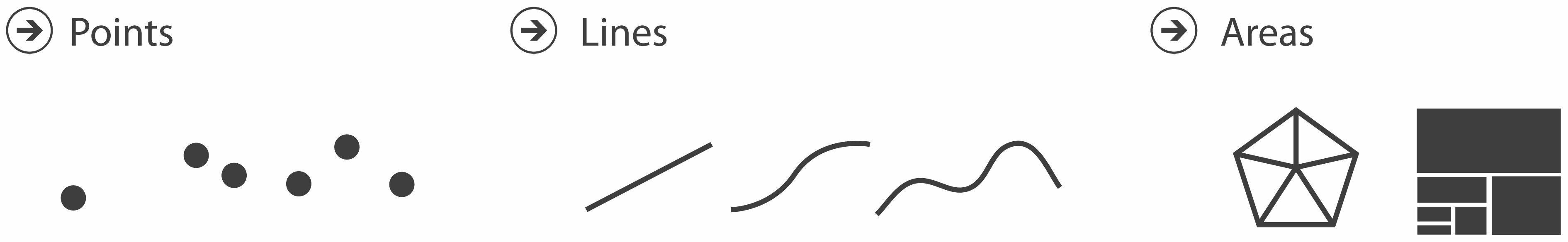
Encoding visually

- analyze idiom structure

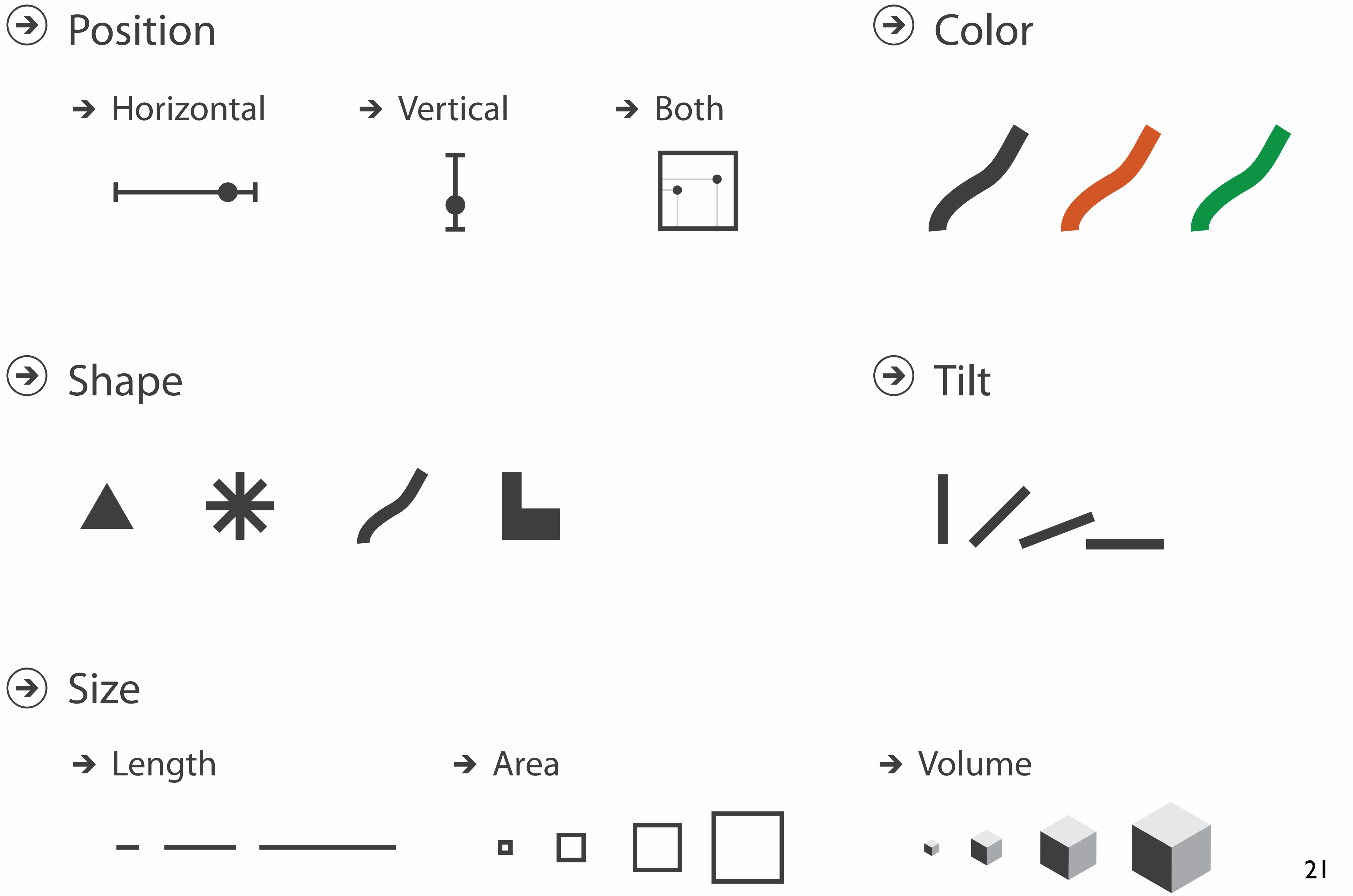
   

Definitions: Marks and channels

- marks
  - geometric primitives

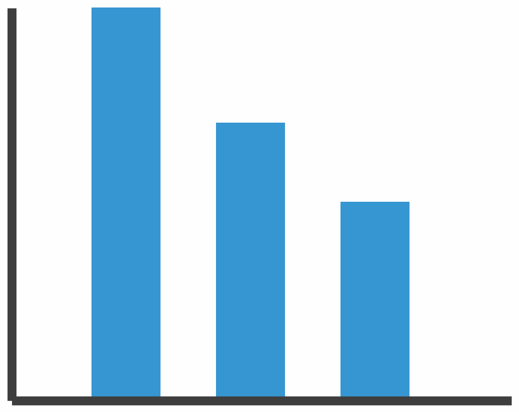


- channels
  - control appearance of marks



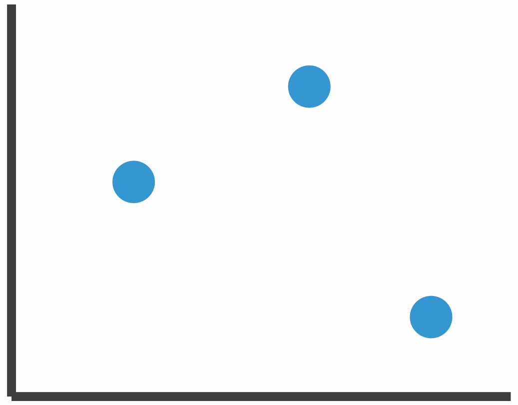
Encoding visually with marks and channels

- analyze idiom structure
  - as combination of marks and channels



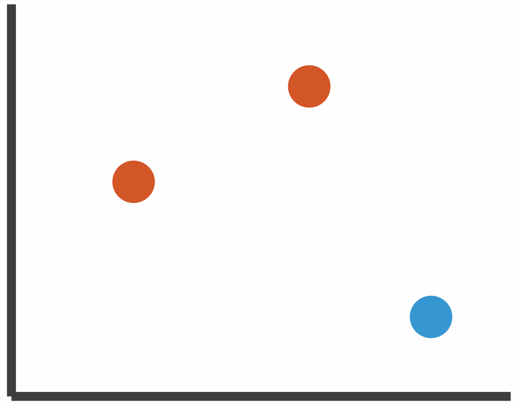
1:
vertical position

mark: line



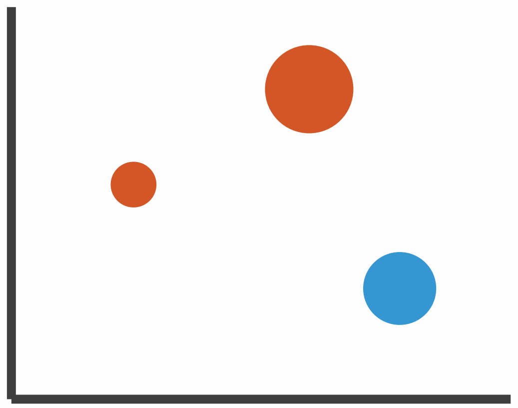
2:
vertical position
horizontal position

mark: point



3:
vertical position
horizontal position
color hue

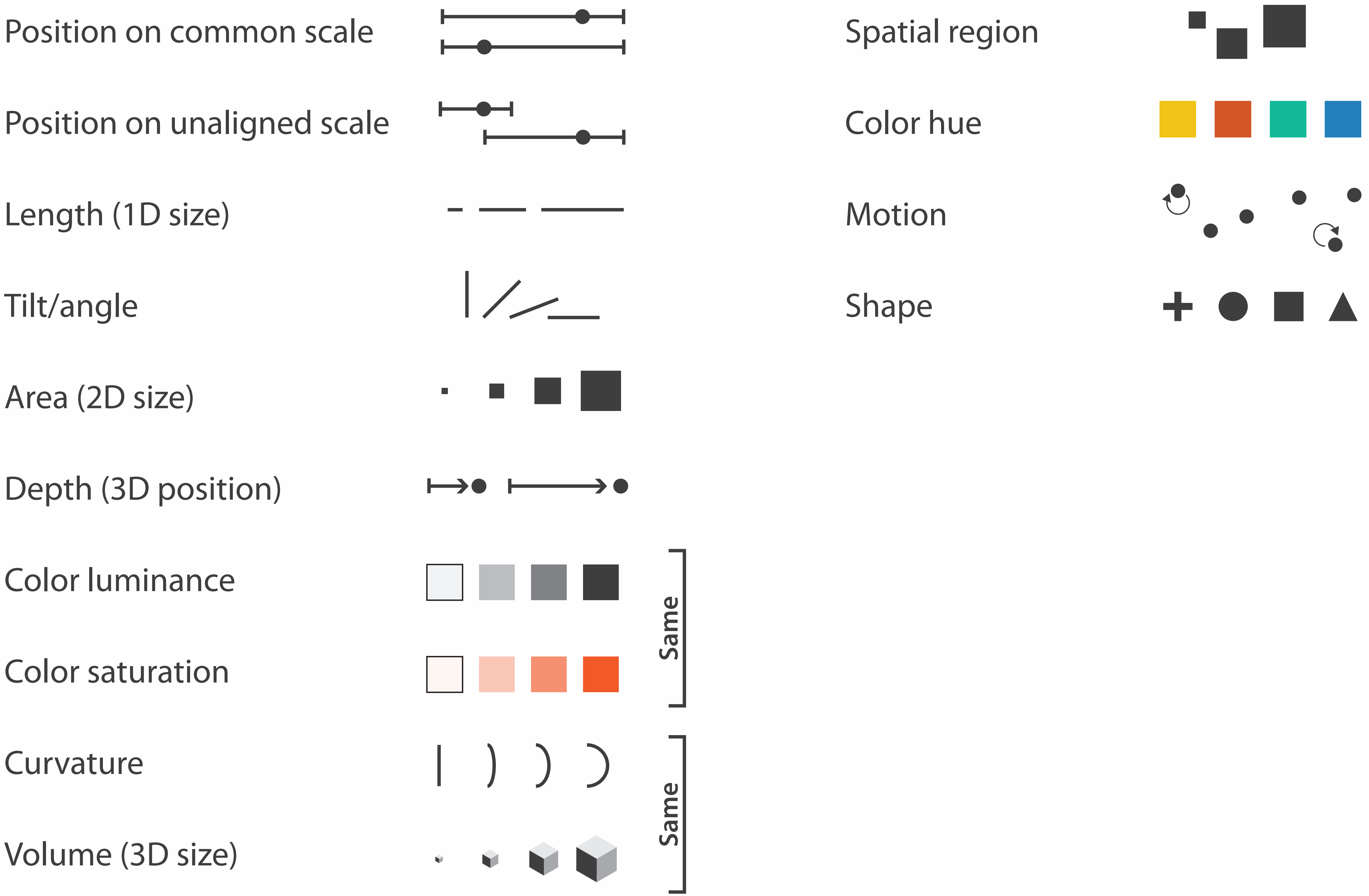
mark: point



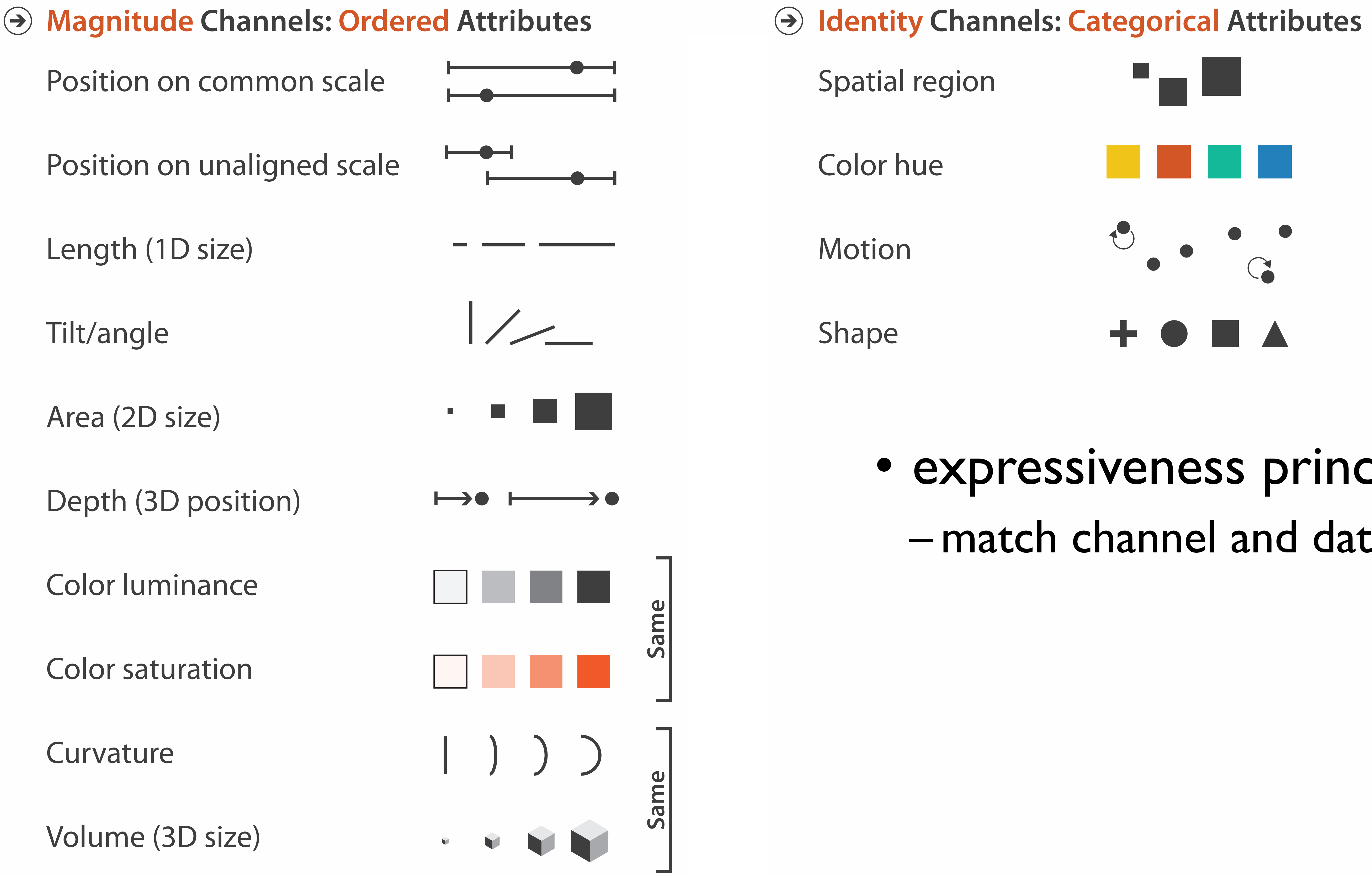
4:
vertical position
horizontal position
color hue
size (area)

mark: point

Channels

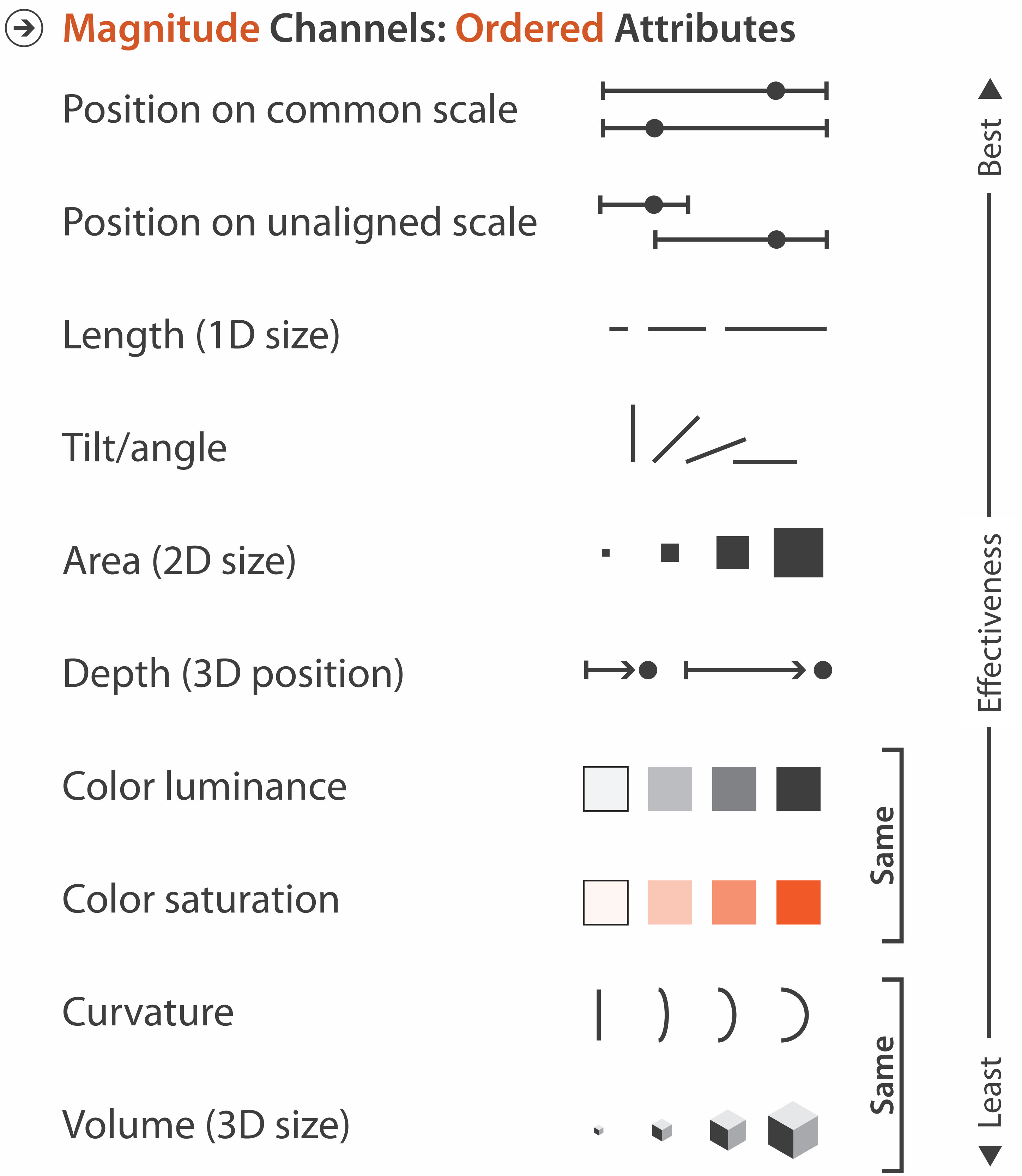

Position on common scale
Position on unaligned scale
Length (1D size)
Tilt/angle
Area (2D size)
Depth (3D position)
Color luminance
Color saturation
Curvature
Volume (3D size)
Same
Same
Spatial region
Color hue
Motion
Shape

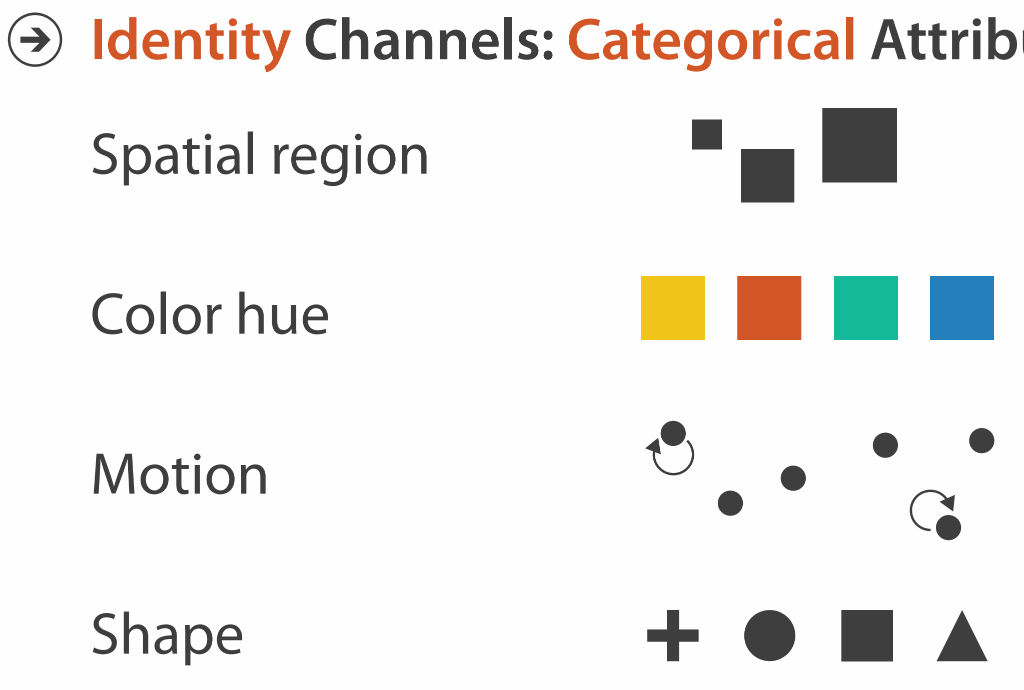
Channels: Matching Types



- expressiveness principle
  - match channel and data characteristics

Channels: Rankings





- expressiveness principle
  - match channel and data characteristics
- effectiveness principle
  - encode most important attributes with highest ranked channels

How?

Encode

➔ **Arrange**
- ➔ Express
- ➔ Separate
- ➔ Order
- ➔ Align
- ➔ Use

➔ **Map**
from categorical and ordered attributes

- ➔ Color
  - ➔ *Hue*
  - ➔ *Saturation*
  - ➔ *Luminance*
- ➔ Size, Angle, Curvature, ...
- ➔ Shape
- ➔ Motion
  Direction, Rate, Frequency, ...

Manipulate

➔ **Change**

➔ **Select**

➔ **Navigate**

Facet

➔ **Juxtapose**

➔ **Partition**

➔ **Superimpose**

Reduce

➔ **Filter**

➔ **Aggregate**

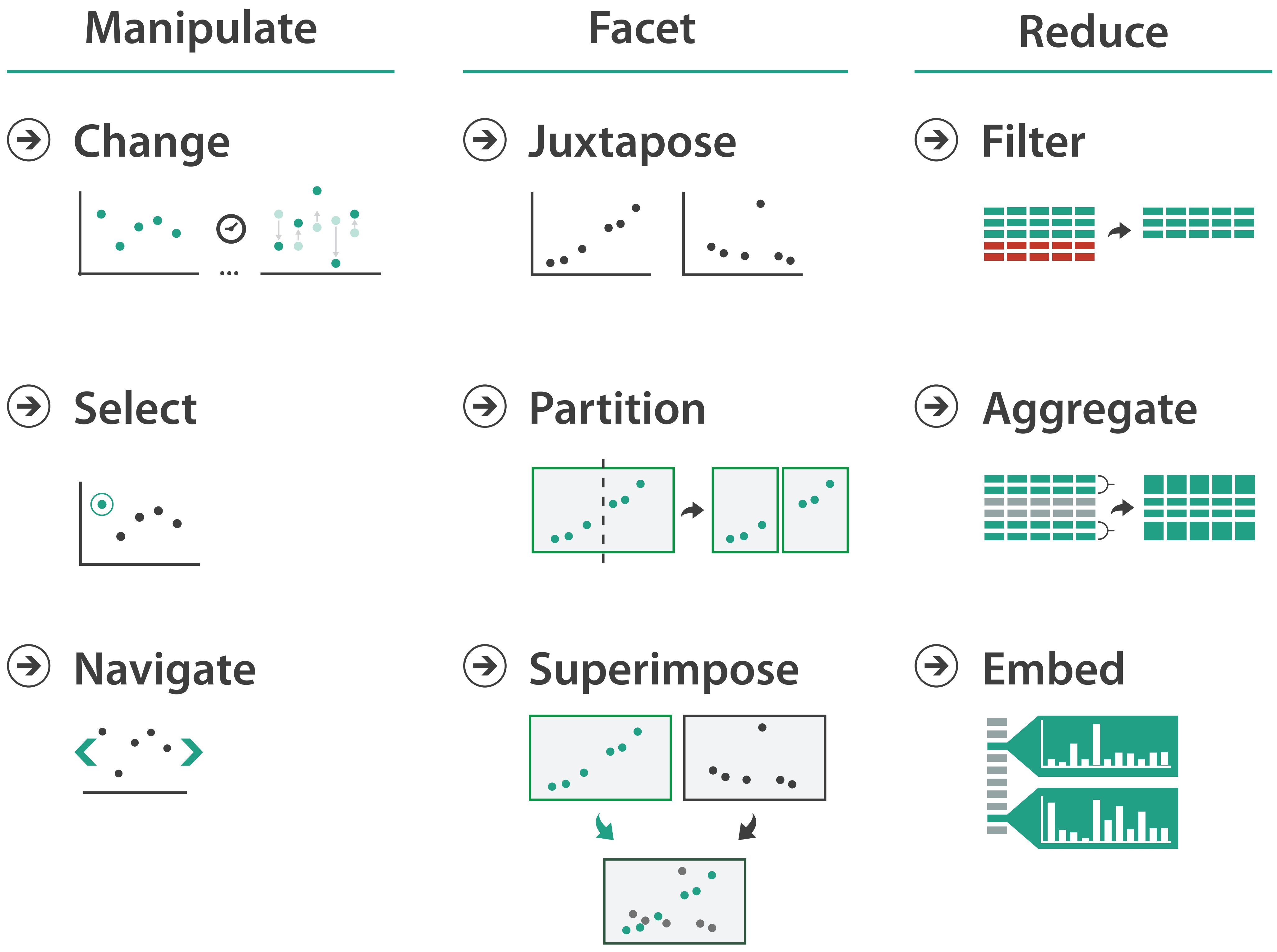
➔ **Embed**

What?

Why?

How?

How to handle complexity: 3 more strategies + 1 previous

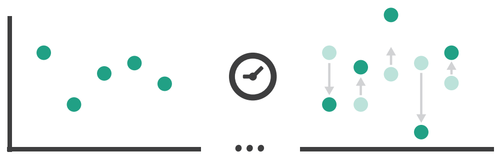


- change view over time
- facet across multiple views
- reduce items/attributes within single view
- derive new data to show within view

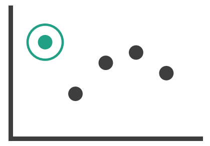
How to handle complexity: 3 more strategies + 1 previous

Manipulate

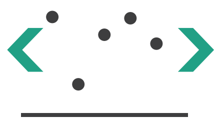
- Change



- Select

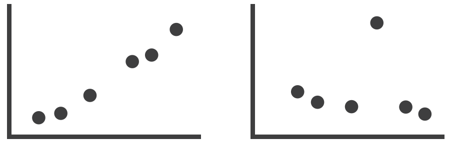


- Navigate

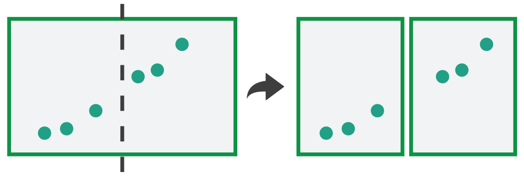


Facet

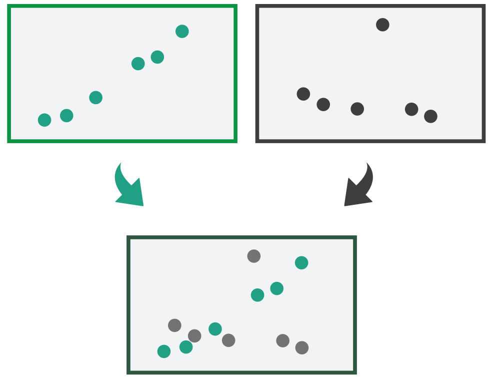
- Juxtapose



- Partition

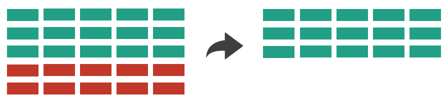


- Superimpose

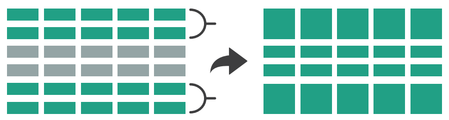


Reduce

- Filter

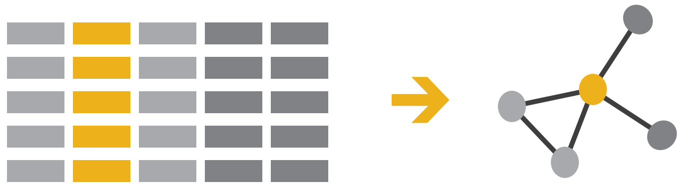


- Aggregate



- Embed

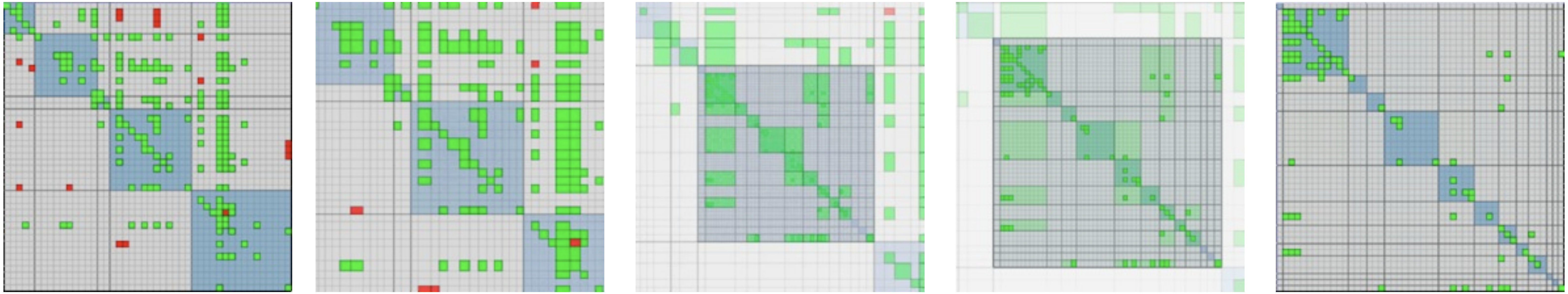
Derive



- change over time
  - most obvious & flexible of the 4 strategies

Idiom: **Animated transitions**

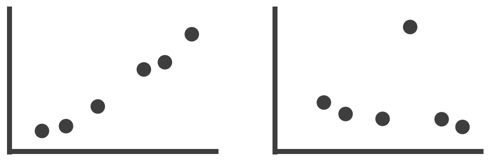
- smooth transition from one state to another
  - alternative to jump cuts
  - support for item tracking when amount of change is limited
- example: multilevel matrix views
  - scope of what is shown narrows down
    - middle block stretches to fill space, additional structure appears within
    - other blocks squish down to increasingly aggregated representations



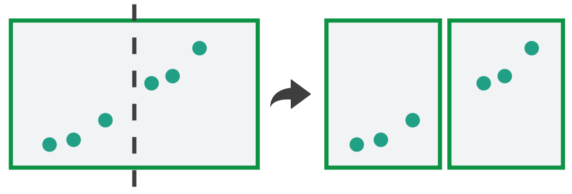
[Using Multilevel Call Matrices in Large Software Projects. van Ham. Proc. IEEE Symp. Information Visualization (InfoVis), pp. 227–232, 2003.]

Facet

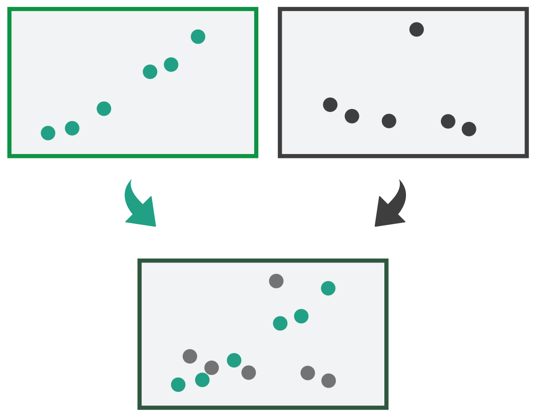
Juxtapose



Partition



Superimpose

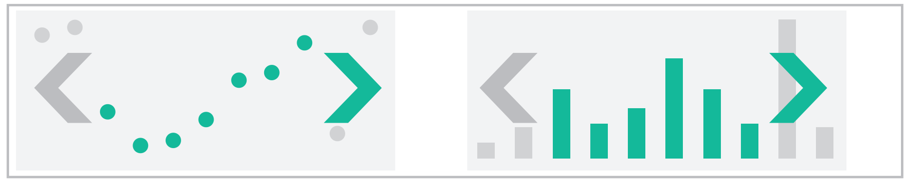


Coordinate Multiple Side By Side Views

- Share Encoding: Same/Different
  - *Linked Highlighting*

- Share Data: All/Subset/None

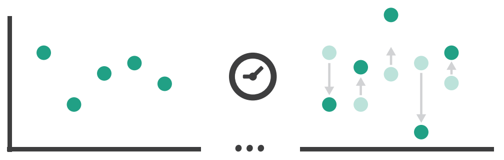
- Share Navigation



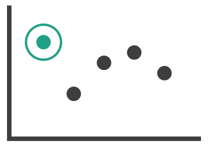
How to handle complexity: 3 more strategies + 1 previous

Manipulate

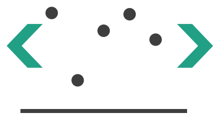
→ Change



→ Select

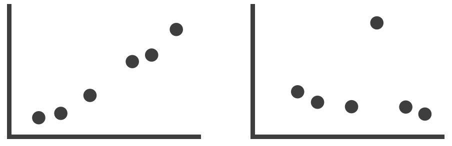


→ Navigate

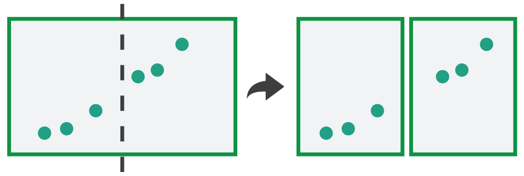


Facet

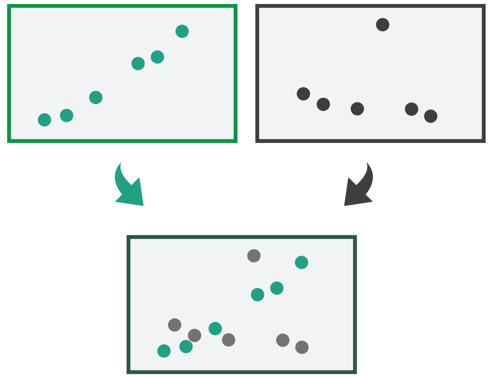
→ Juxtapose



→ Partition

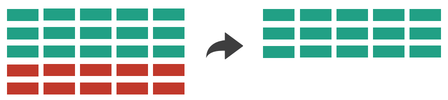


→ Superimpose

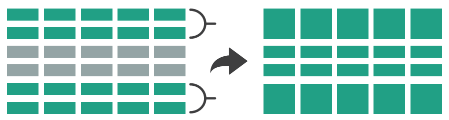


Reduce

→ Filter

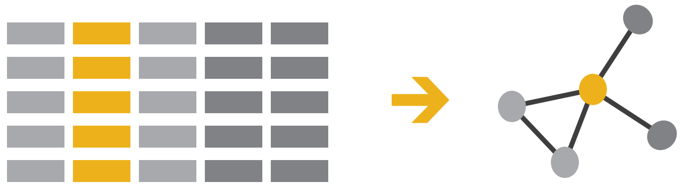


→ Aggregate



→ Embed

→ *Derive*

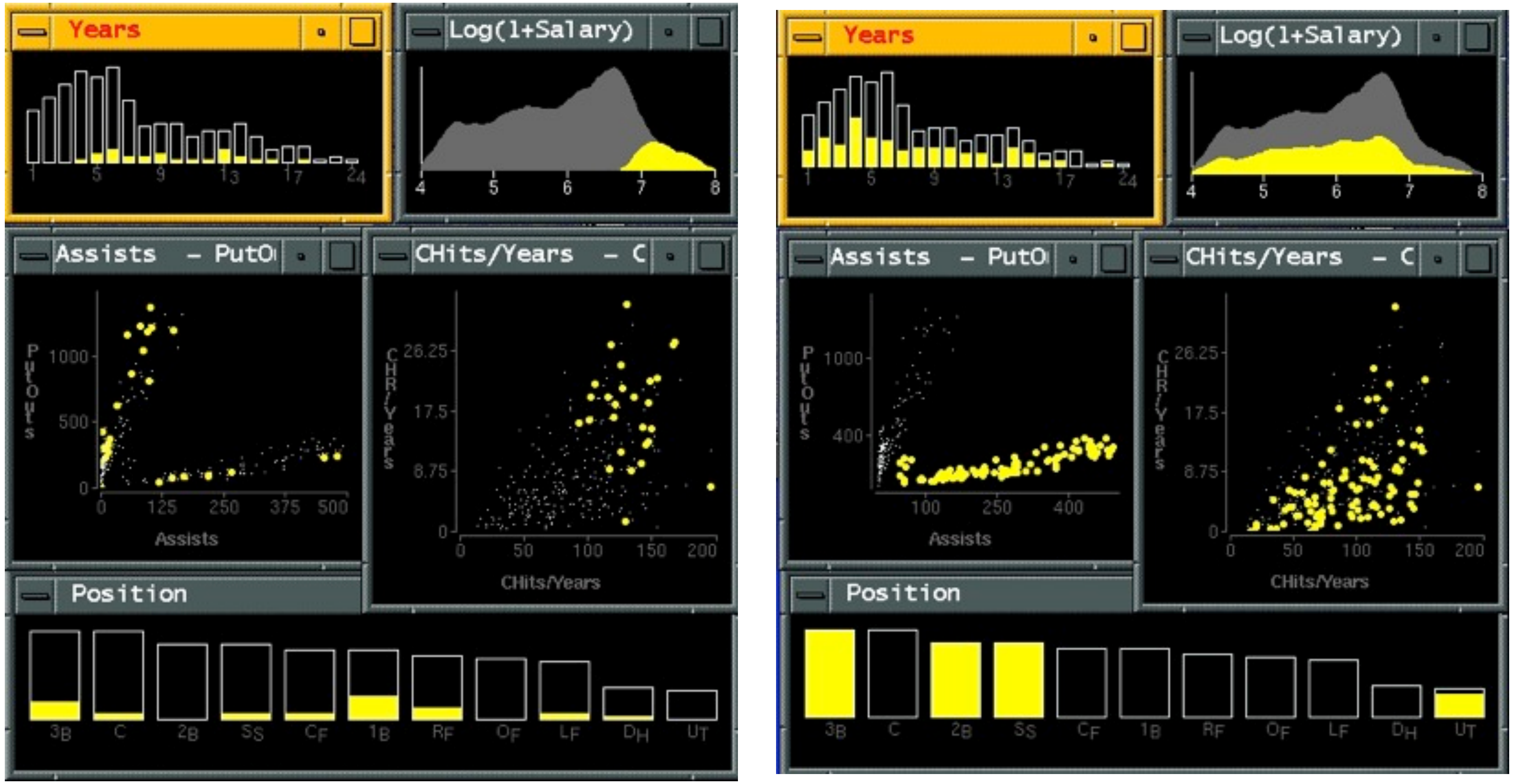


- facet data across multiple views

Idiom: **Linked highlighting**

System: **EDV**

- see how regions contiguous in one view are distributed within another
  - powerful and pervasive interaction idiom
- encoding: different
  - ***multiform***
- data: all shared



[Visual Exploration of Large Structured Datasets. Wills. Proc. New Techniques and Trends in Statistics (NTTS), pp. 237–246. IOS Press, 1995.]

Idiom: **bird's-eye maps** System: **Google Maps**

- encoding: same
- data: subset shared
- navigation: shared
  - bidirectional linking

- differences
  - viewpoint
  - (size)

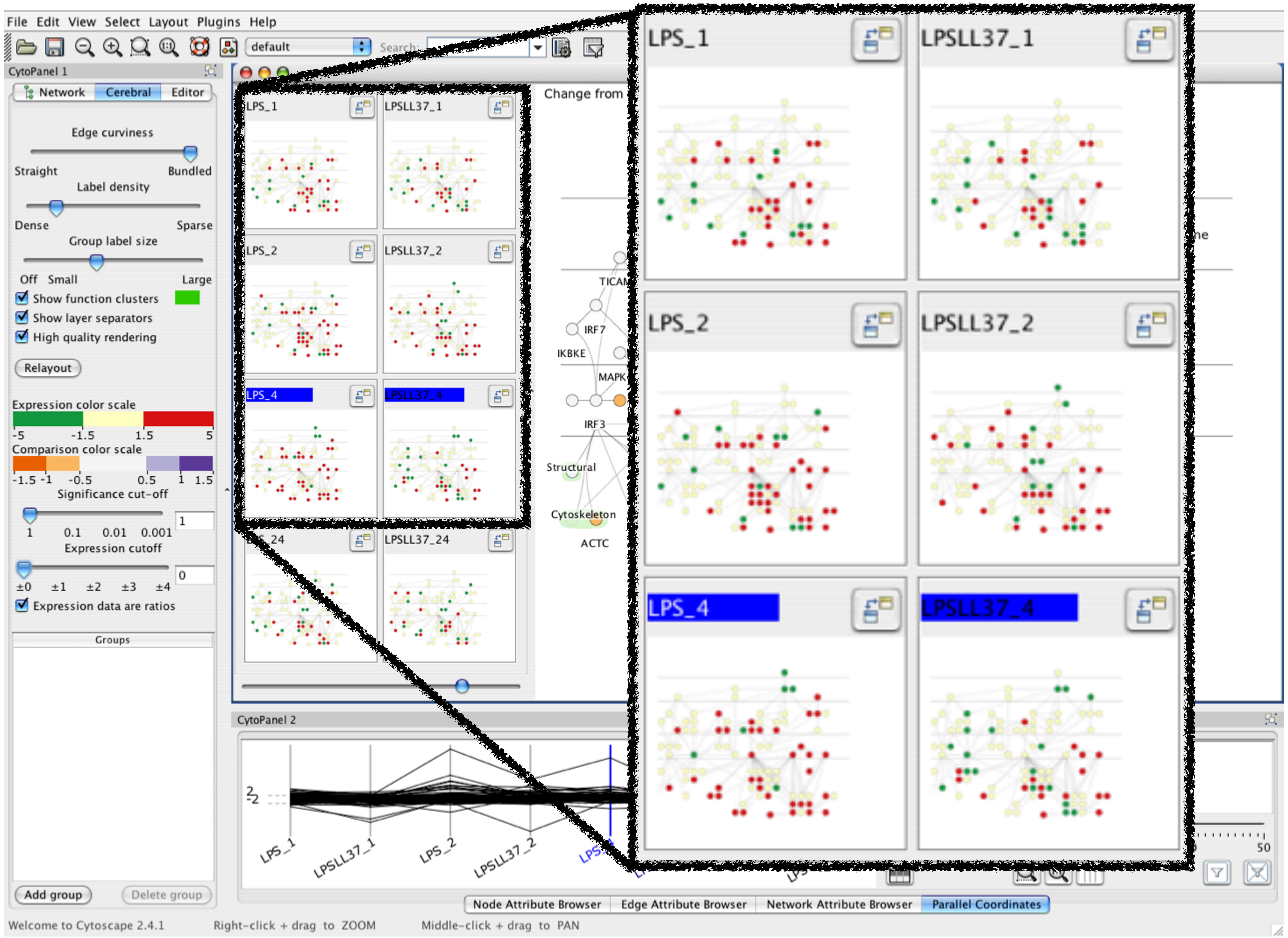
- ***overview-detail***

[A Review of Overview+Detail, Zooming, and Focus+Context Interfaces. Cockburn, Karlson, and Bederson. ACM Computing Surveys 41:1 (2008), 1–31.]

Idiom: **Small multiples**

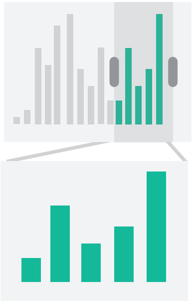
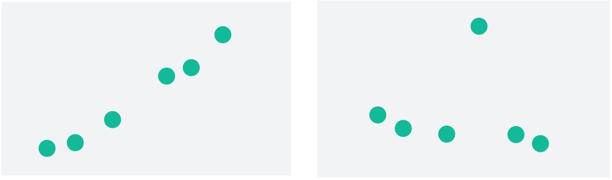
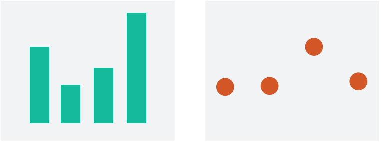
System: **Cerebral**

- encoding: same
- data: none shared
  - different attributes for node colors
  - (same network layout)
- navigation: shared



[Cerebral: Visualizing Multiple Experimental Conditions on a Graph with Biological Context. Barsky, Munzner, Gardy, and Kincaid. IEEE Trans. Visualization and Computer Graphics (Proc. InfoVis 2008) 14:6 (2008), 1253–1260.]

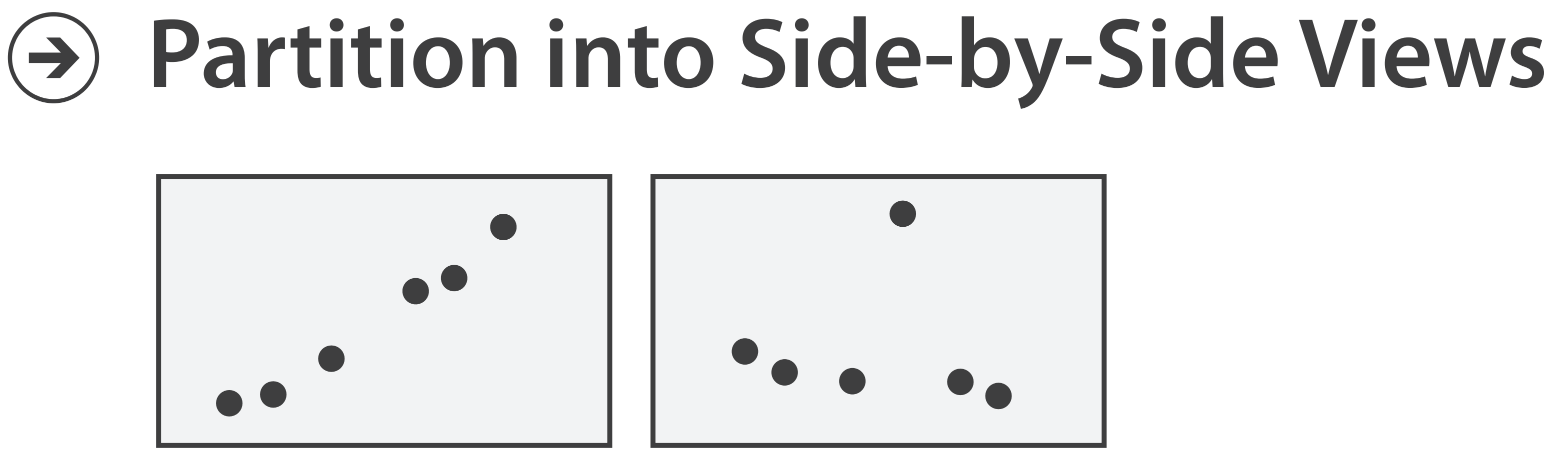
Coordinate views: Design choice interaction

		Data		
		All	Subset	None
Encoding	Same	Redundant	 Overview/ Detail	 Small Multiples
	Different	 Multiform	 Multiform, Overview/ Detail	No Linkage

- why juxtapose views?
  - benefits: eyes vs memory
    - lower cognitive load to move eyes between 2 views than remembering previous state with single changing view
  - costs: display area, 2 views side by side each have only half the area of one view

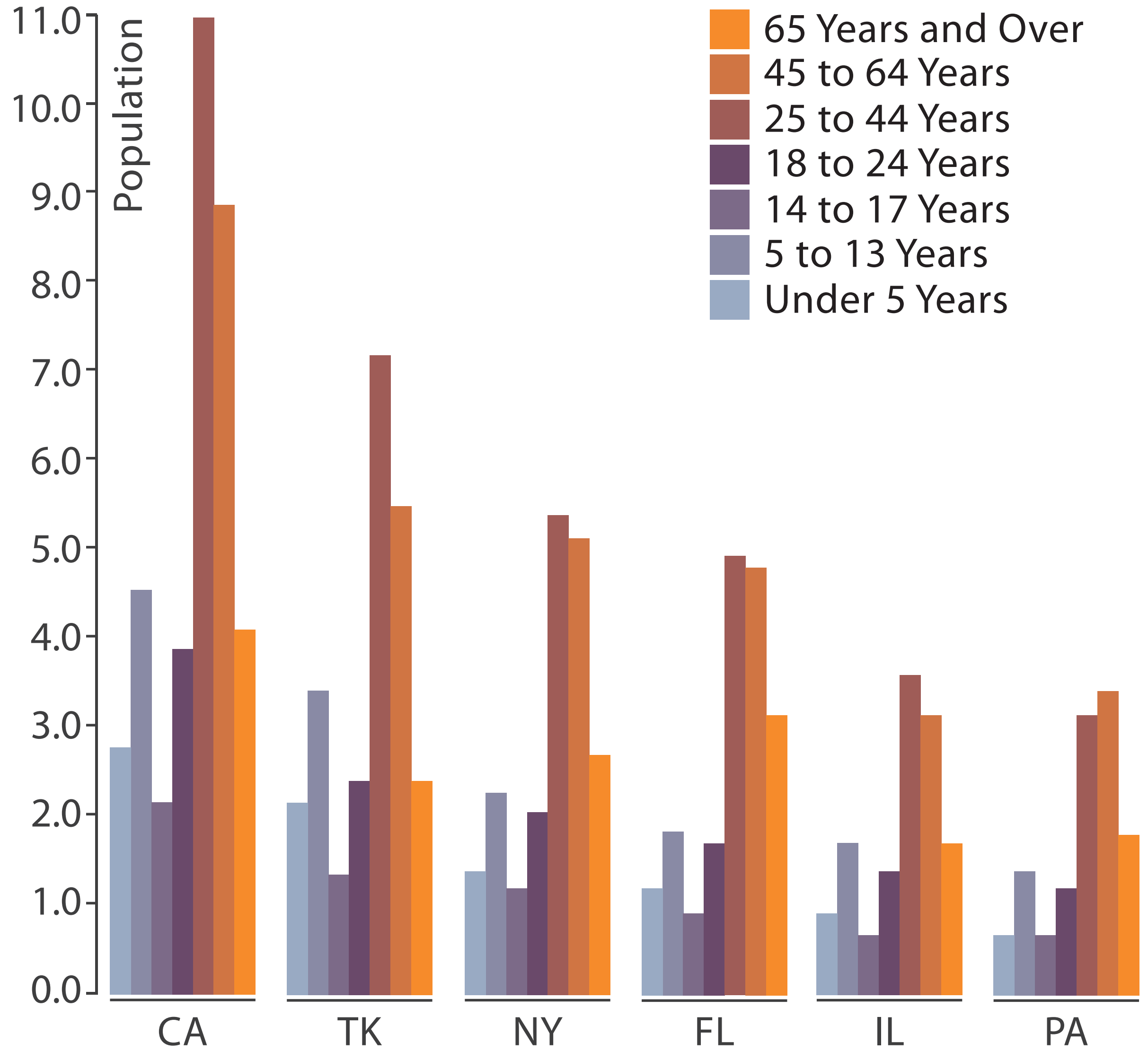
Partition into views

- how to divide data between views
  - encodes association between items using spatial proximity
  - major implications for what patterns are visible
  - split according to attributes
- design choices
  - how many splits
    - all the way down: one mark per region?
    - stop earlier, for more complex structure within region?
  - order in which attribs used to split
  - how many views

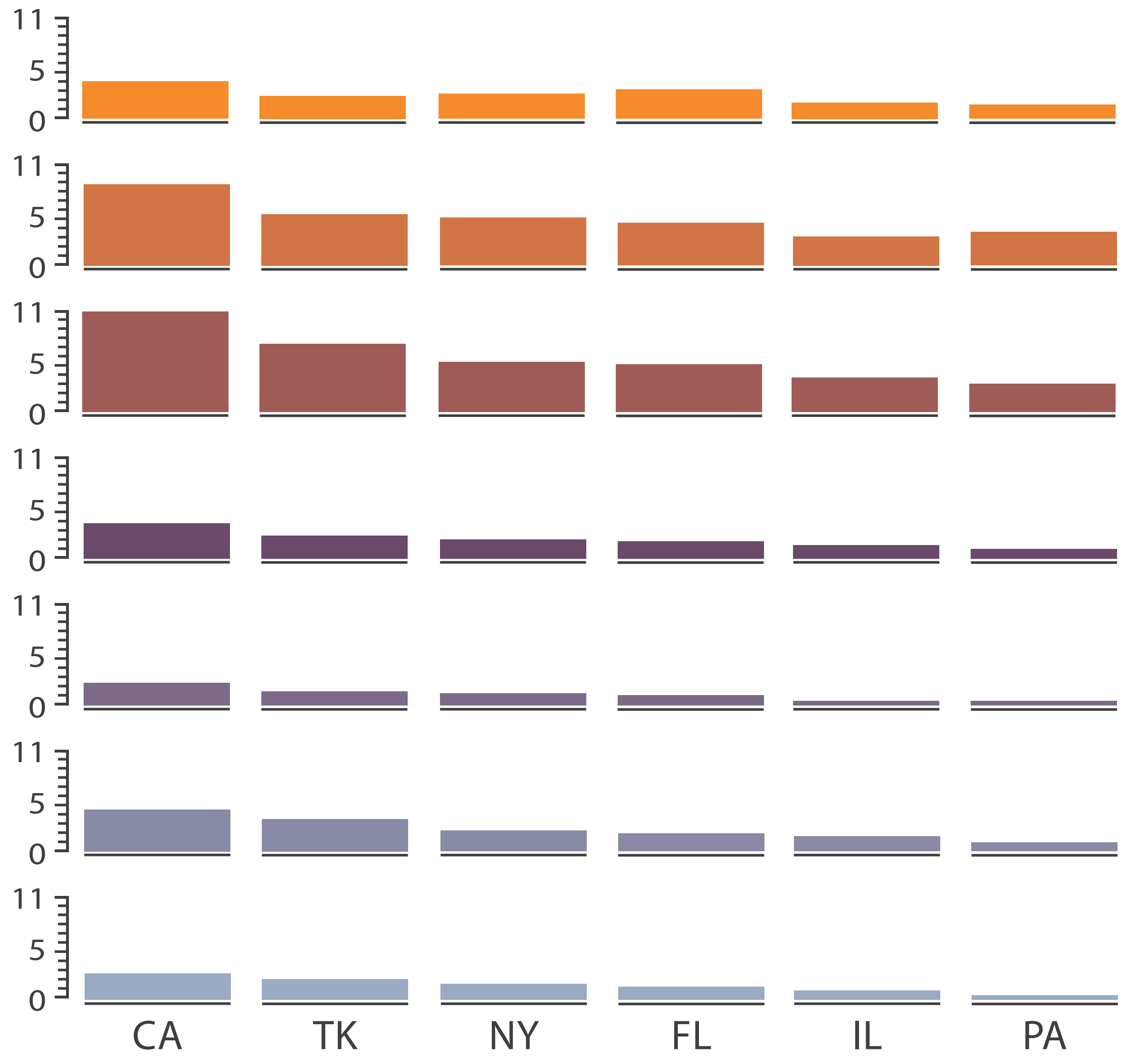


Partitioning: List alignment

- single bar chart with grouped bars
  - split by state into regions
    - complex glyph within each region showing all ages
  - compare: easy within state, hard across ages



- small-multiple bar charts
  - split by age into regions
    - one chart per region
  - compare: easy within age, harder across states



Partitioning: Recursive subdivision

System: **HIVE**

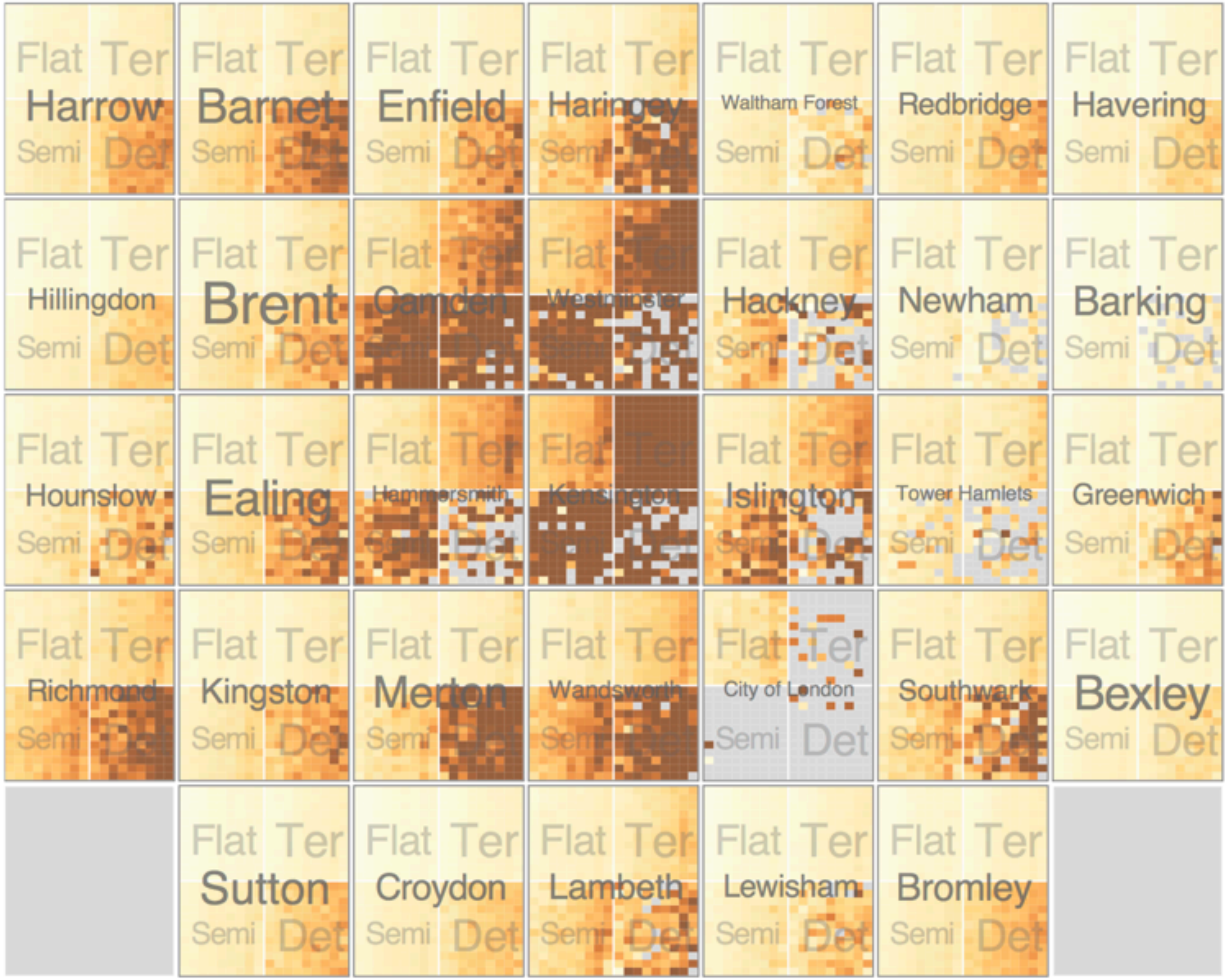
- split by type
- then by neighborhood
- then time
  - years as rows
  - months as columns

[Configuring Hierarchical Layouts to Address Research Questions. Slingsby, Dykes, and Wood. IEEE Transactions on Visualization and Computer Graphics (Proc. InfoVis 2009) 15:6 (2009), 977–984.]

Partitioning: Recursive subdivision

System: **HIVE**

- switch order of splits
  - neighborhood then type
- very different patterns

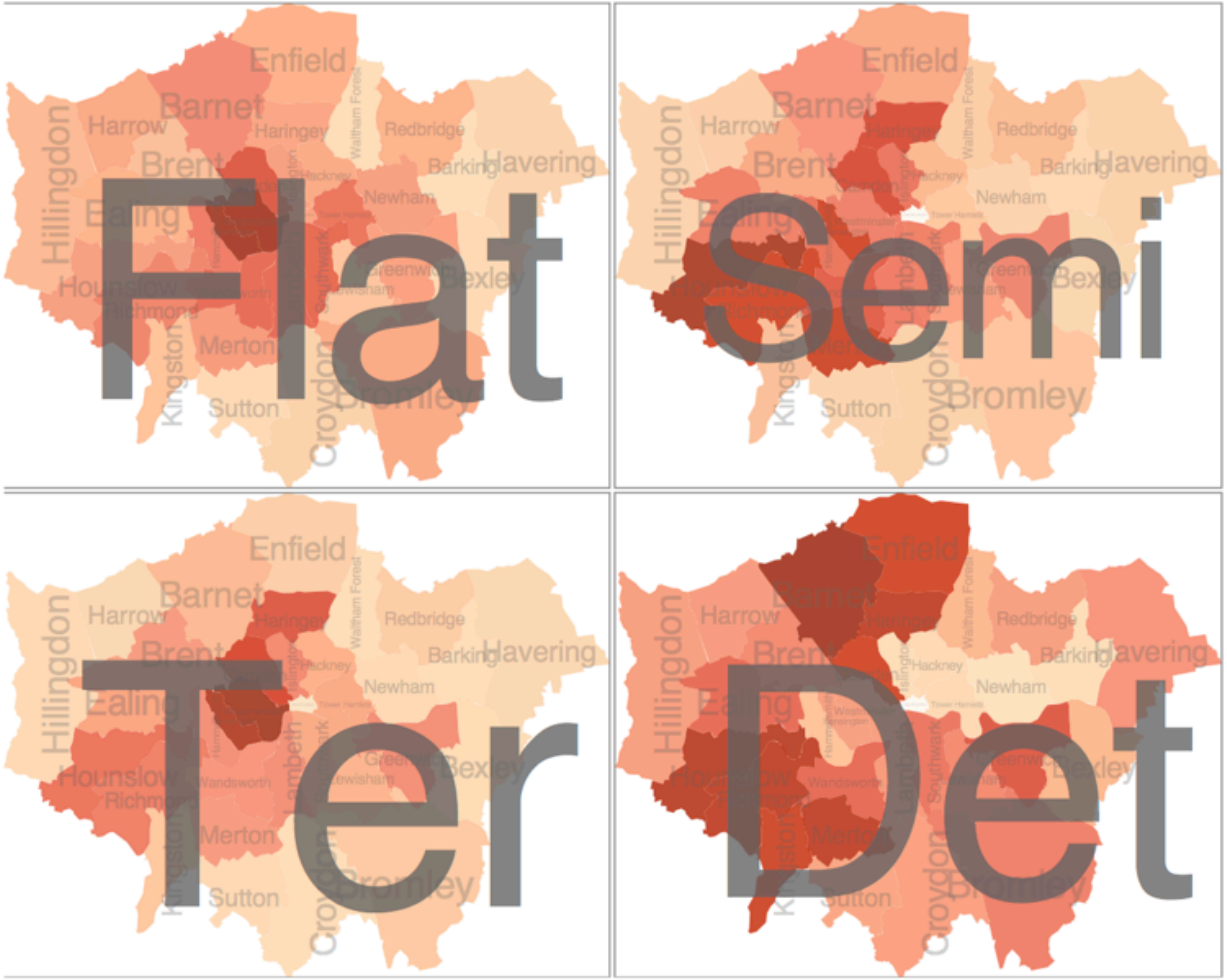


[Configuring Hierarchical Layouts to Address Research Questions. Slingsby, Dykes, and Wood. IEEE Transactions on Visualization and Computer Graphics (Proc. InfoVis 2009) 15:6 (2009), 977–984.]

Partitioning: Recursive subdivision

System: **HIVE**

- different encoding for second-level regions
  - choropleth maps

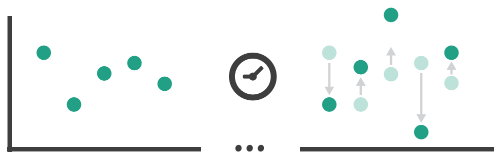


[Configuring Hierarchical Layouts to Address Research Questions. Slingsby, Dykes, and Wood. IEEE Transactions on Visualization and Computer Graphics (Proc. InfoVis 2009) 15:6 (2009), 977–984.]

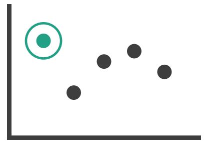
How to handle complexity: 3 more strategies + 1 previous

Manipulate

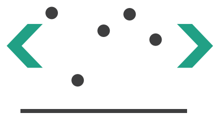
Change



Select

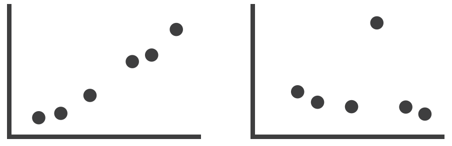


Navigate

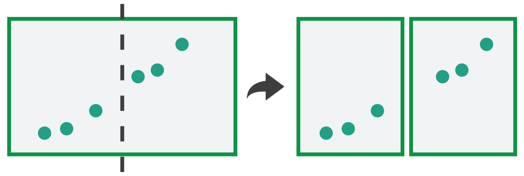


Facet

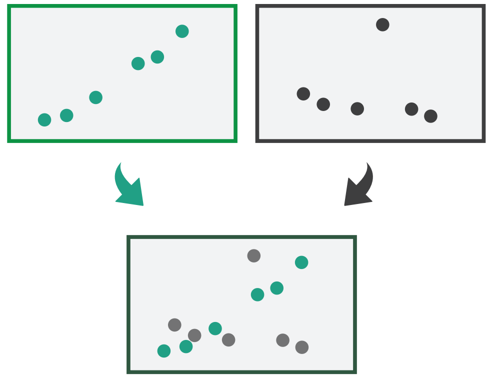
Juxtapose



Partition

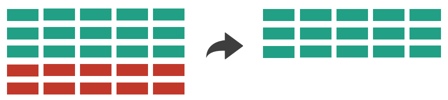


Superimpose

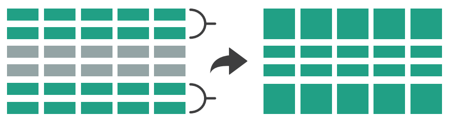


Reduce

Filter

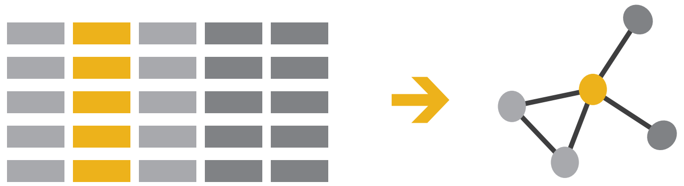


Aggregate



Embed

Derive

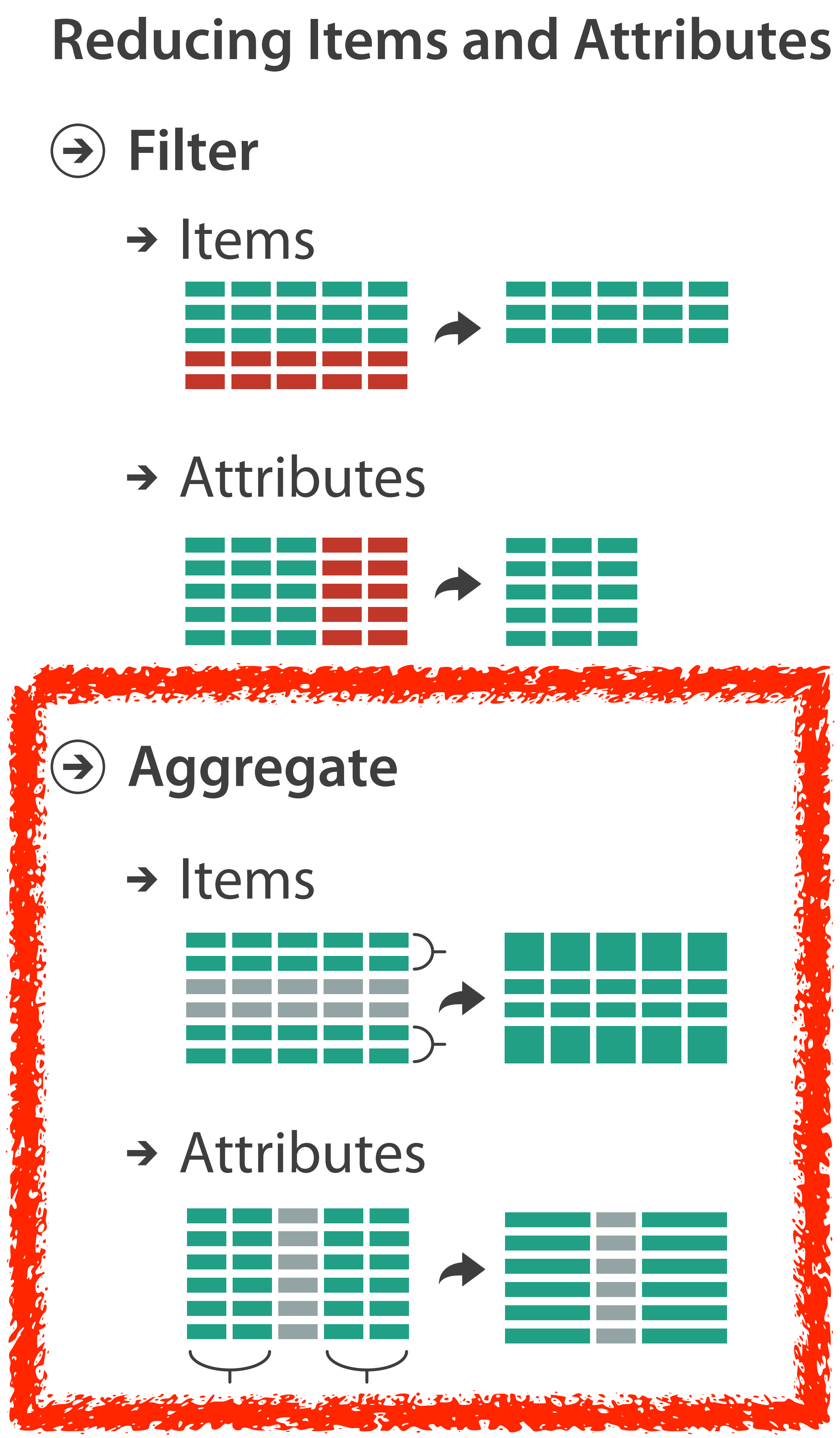


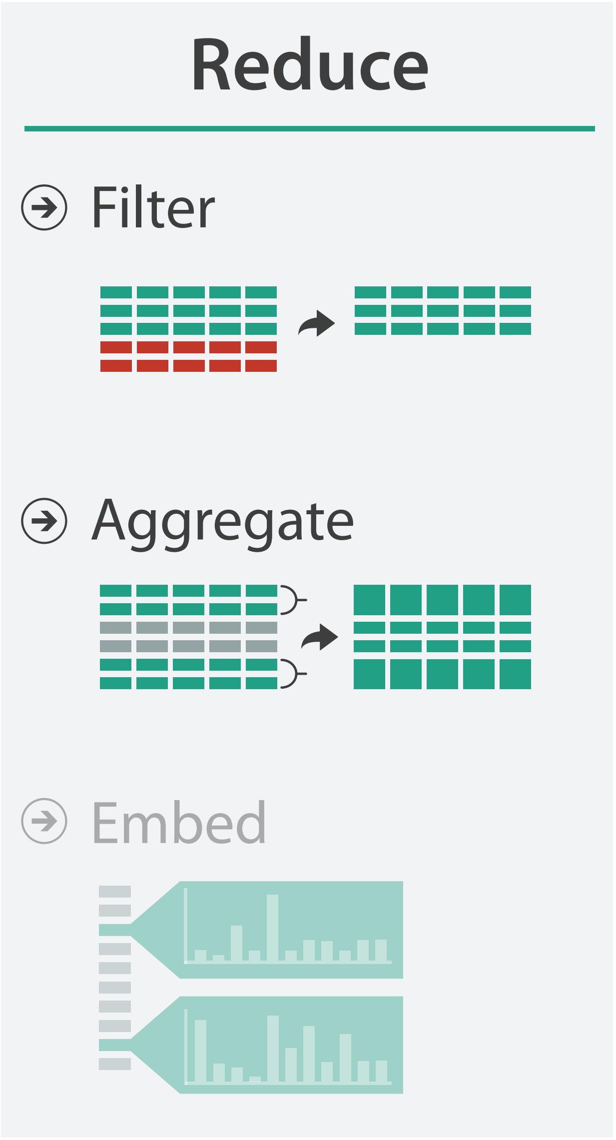
- reduce what is shown within single view

Reduce items and attributes

- reduce/increase: inverses
- filter
  - pro: straightforward and intuitive
    - to understand and compute
  - con: out of sight, out of mind
- aggregation
  - pro: inform about whole set
  - con: difficult to avoid losing signal

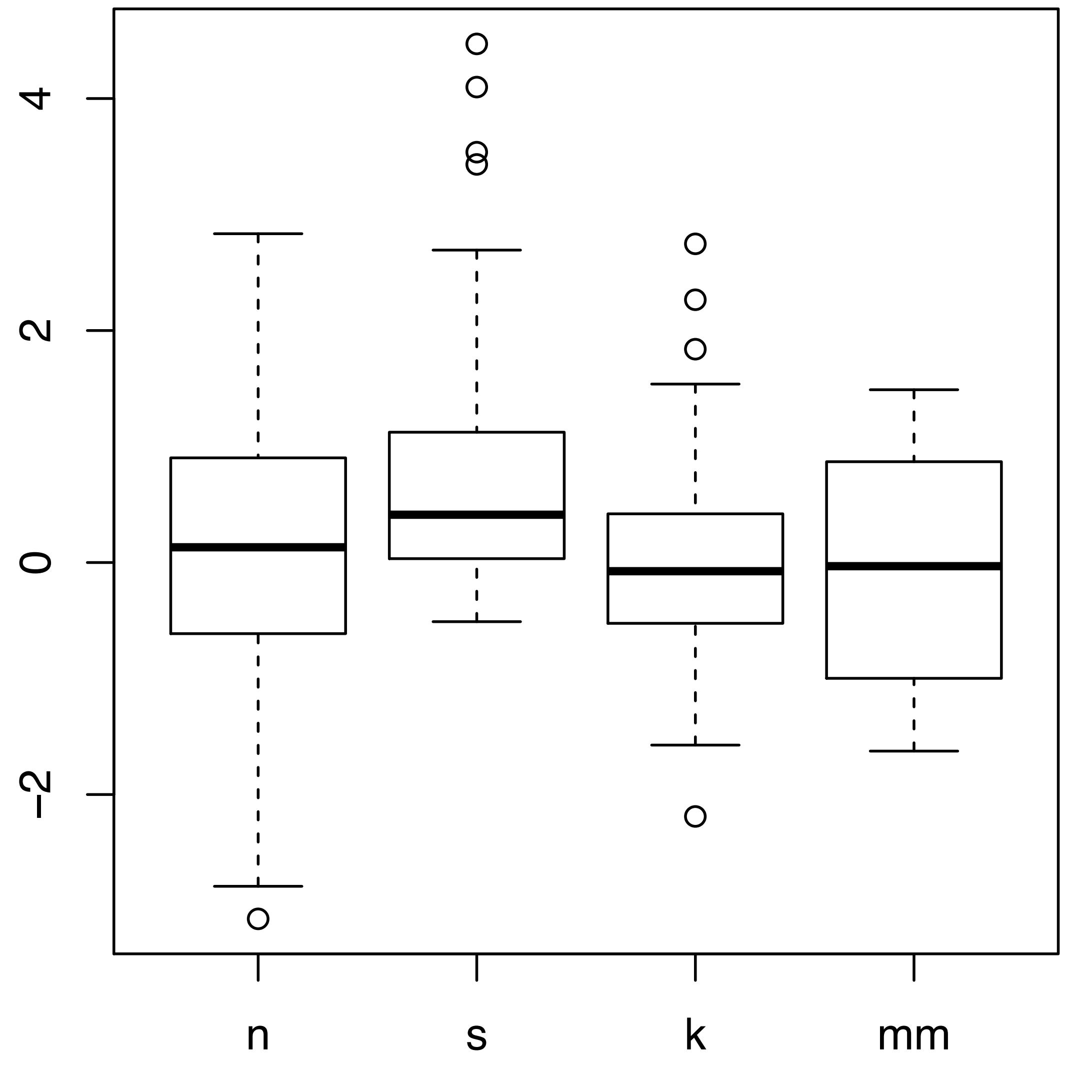
- not mutually exclusive
  - combine filter, aggregate
  - combine reduce, facet, change, derive





Idiom: **boxplot**

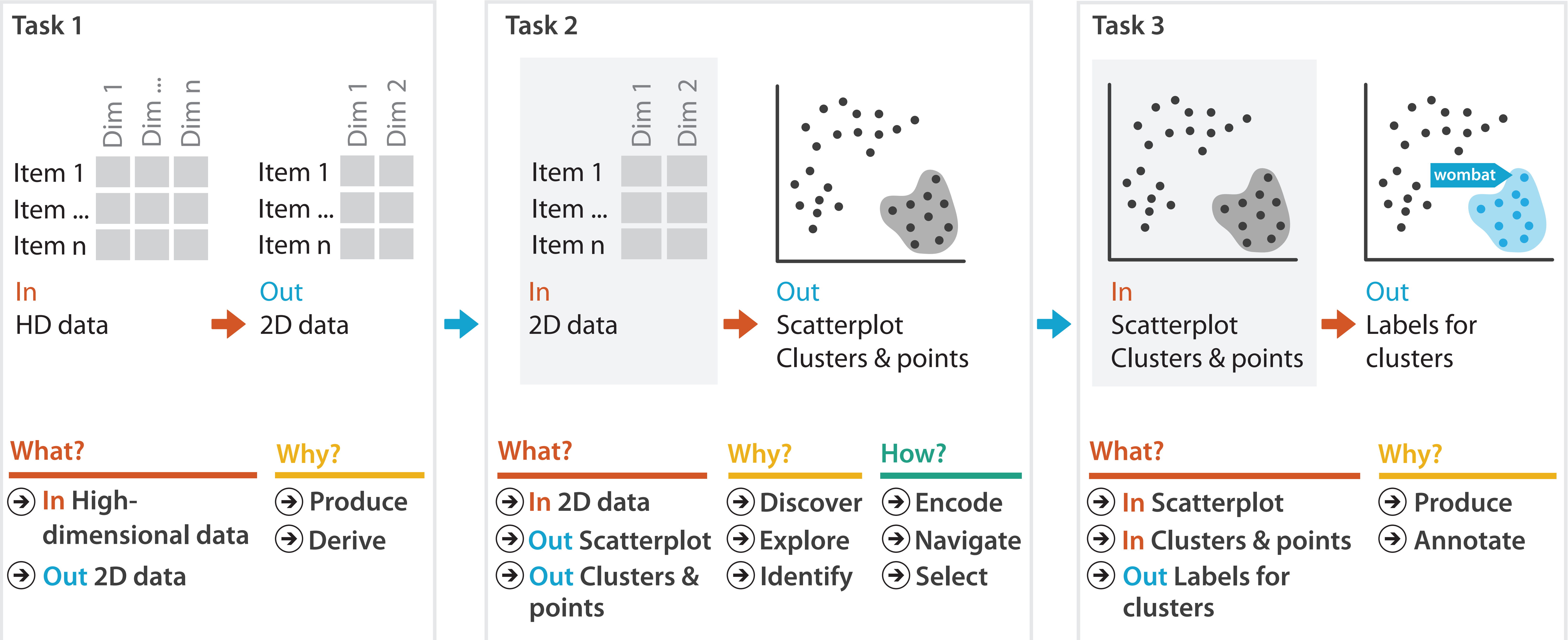
- static item aggregation
- task: find distribution
- data: table
- derived data
  - 5 quant attribs
    - median: central line
    - lower and upper quartile: boxes
    - lower upper fences: whiskers
      - values beyond which items are outliers
  - outliers beyond fence cutoffs explicitly shown

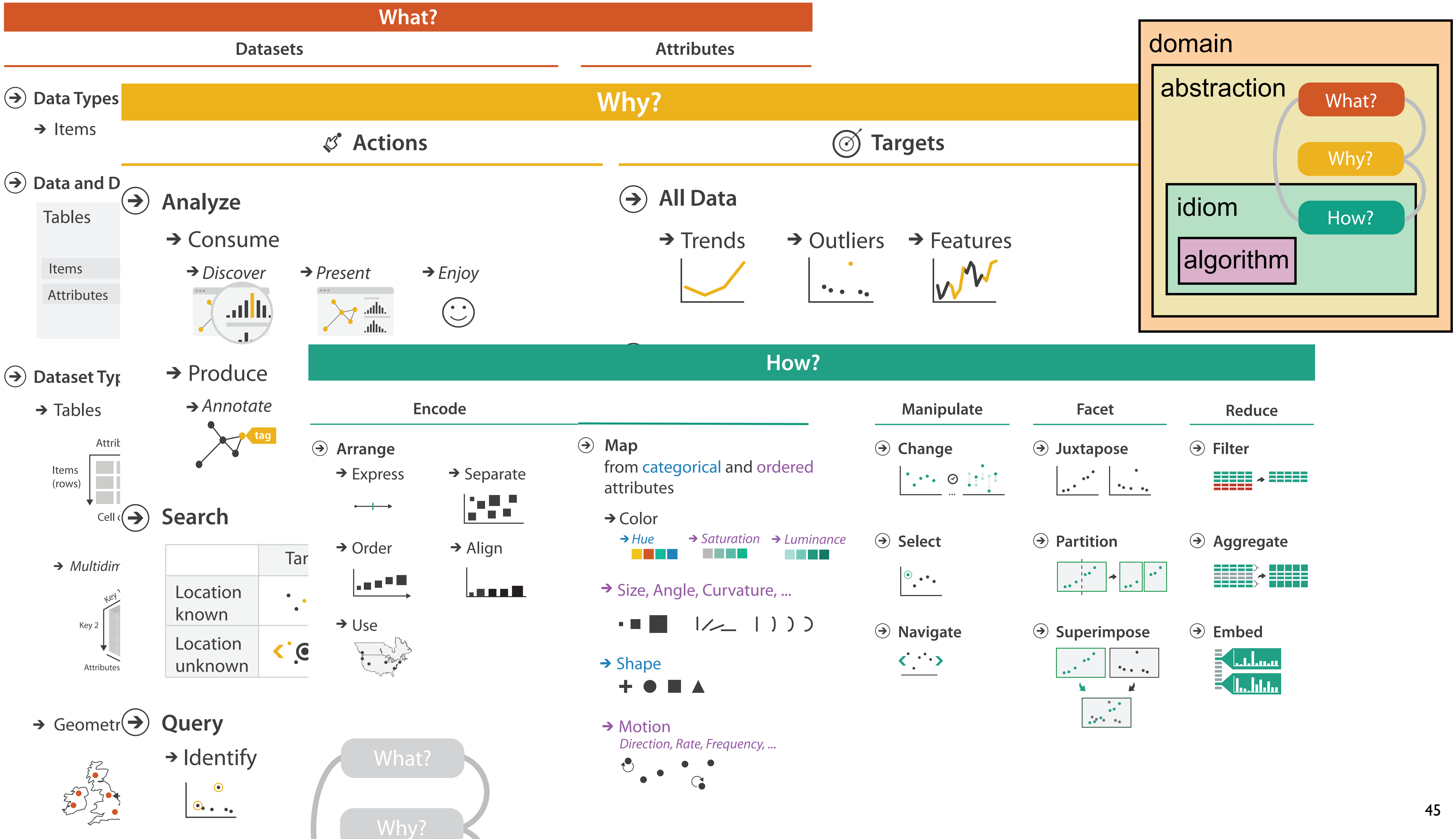


[40 years of boxplots. Wickham and Stryjewski. 2012. had.co.nz]

Idiom: **Dimensionality reduction for documents**

- attribute aggregation
  - derive low-dimensional target space from high-dimensional measured space




What?
Datasets
Attributes
Data Types
Items
Data and D
Tables
Items
Attributes
Dataset Typ
Tables
Attrib
Items (rows)
Cell c
Multidim
Key 1
Key 2
Attributes
Geometr
Why?
Actions
Targets
Analyze
Consume
Discover
Present
Enjoy
Produce
Annotate
tag
Search
Tar
Location known
Location unknown
Query
Identify
All Data
Trends
Outliers
Features
domain
abstraction
What?
Why?
idiom
How?
algorithm
How?
Encode
Manipulate
Facet
Reduce
Arrange
Express
Separate
Order
Align
Use
Map
from categorical and ordered attributes
Color
Hue
Saturation
Luminance
Size, Angle, Curvature, ...
Shape
Motion
Direction, Rate, Frequency, ...
Change
Select
Navigate
Juxtapose
Partition
Superimpose
Filter
Aggregate
Embed
What?
Why?

More Information

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  http://www.cs.ubc.ca/~tmm/vadbook
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  - illustrations: Eamonn Maguire

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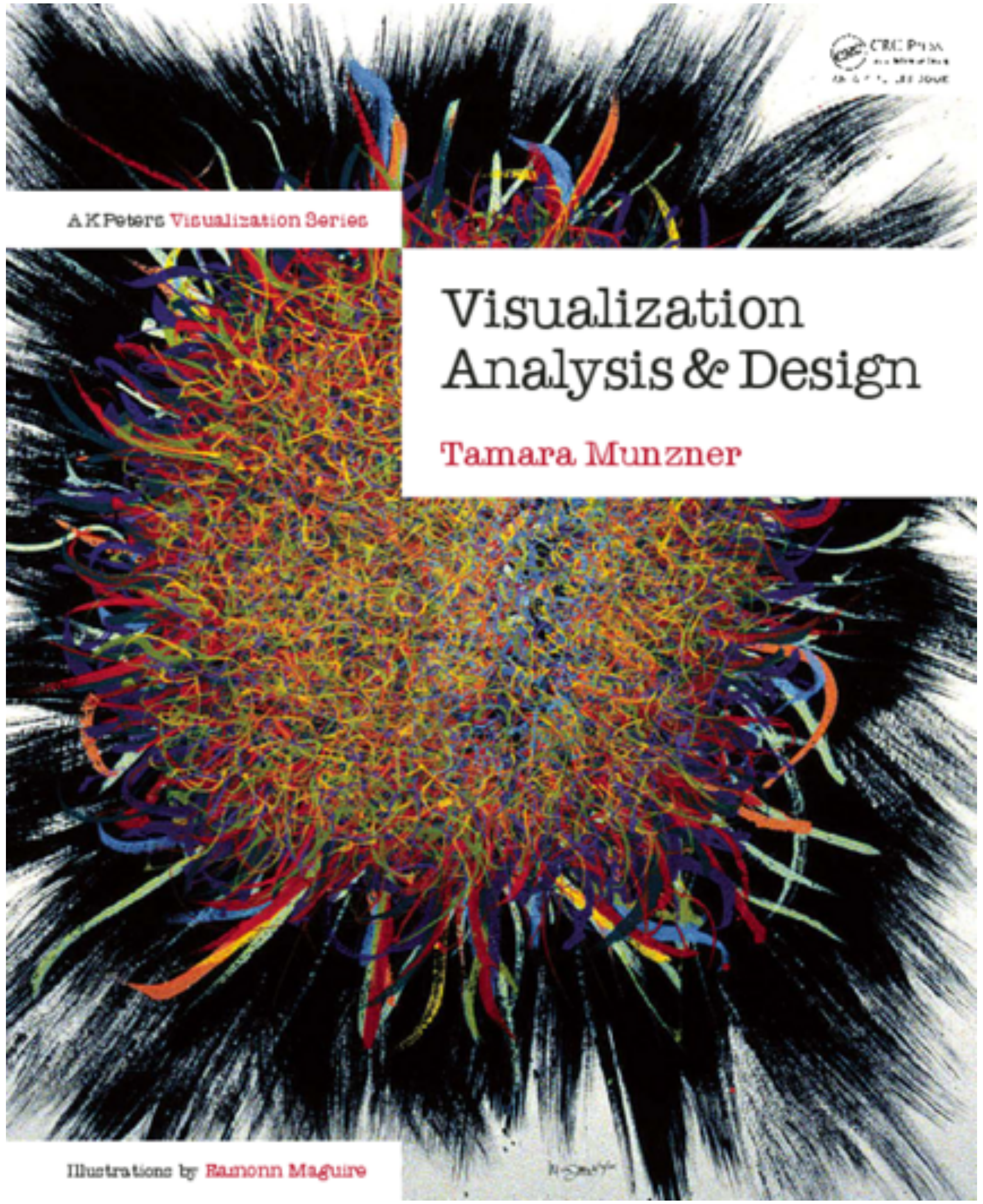
  http://www.cs.ubc.ca/group/infovis
  http://www.cs.ubc.ca/~tmm



Visualization Analysis and Design.
Munzner. A K Peters Visualization Series, CRC Press, Visualization Series, 2014.